HEALTH AND CONDITION OF JUVENILE CHINOOK AND CHUM SALMON NEAR THE CHENA RIVER DAM, ALASKA

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# HEALTH AND CONDITION OF JUVENILE CHINOOK AND CHUM SALMON NEAR THE CHENA RIVER DAM, ALASKA

A

THESIS

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# ABSTRACT

During May-June, 1995 and 1996, outmigrating chum salmon, *Oncorhynchus keta*, and chinook salmon, *O. tschawytscha*, were captured in the Chena River near the Chena River Lakes Flood Control Project. Fish condition was determined through the investigation of physical injury and scale loss. Except for one sample, the proportion of injured fish was never greater than 7% for chum or chinook salmon. Few injuries were severe. The proportion of chinook salmon with scale loss ranged from 1-33%, most of which were only partially descaled. When significant length differences existed, injured, descaled, and partially descaled fish were always larger than non-injured and non-descaled fish. Arctic grayling (*Thymallus arcticus*) diet by weight consisted of chum salmon (2%), invertebrates (89%), other fish (3%), and miscellaneous material (6%). Plasma cortisol levels were used as an indicator of the primary stress response of chinook salmon and did not indicate any unusual physiological stress level.

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# Introduction

## Background

The Chena River Lakes Flood Control Project (herein called the Chena River Dam) was authorized in 1968 (completed in 1973) and was designed to protect Fairbanks, Alaska, from flooding by the Chena River. The main features of the project are an 11.3-km diversion dam across the Chena River in the vicinity of North Pole, Alaska, and a 33.3-km system of levees and groins along the nearby Tanana River. The diversion dam includes flood control gates on the Chena River and a cleared floodway that contains a temporary reservoir of floodwater when the gates are partially closed to control downstream discharge (i.e., a control event). The maximum flow objective for the Chena River Dam is 406 $m^3/s$ (12,000 cfs) through downtown Fairbanks.

Thus far, the three largest control events were in 1985, 1991, and 1992, all during the spring breakup period (May-early June) when juvenile chum salmon, *Oncorhynchus keta*, and juvenile chinook salmon, *O. tschawytscha*, begin downstream migration to the Bering Sea. Chum salmon outmigrate soon after hatching, at age 0, during peak flow associated with spring breakup. Chinook salmon outmigrate as age-1 or age-2 juveniles over a longer period, but primarily May and June.

Public concern has been expressed that control events during spring may affect these outmigrants through delay and, ultimately, increased mortality. During 1981-1983, the U.S. Fish and Wildlife Service documented the timing and duration of outmigration just downstream of the floodgates, but this study was not designed to evaluate the effects of Project operation on outmigration or abundance (Williamson 1984).

Study Area

During summer 1994, feasibility studies were conducted to evaluate potential study sites upstream and downstream of the Chena River Dam. A primary sampling location for each area was chosen with three criteria in mind: efficiency of capture, safety for field personnel, ease of accessibility. An upstream site was selected next to a bluff at the end of an access trail which originates at the north end of the dam (Figure 1). The channel morphology of this area provides a deepwater channel for trapping juvenile salmon with adjacent high ground to insure a secure camp during a control event. This location is far enough upstream to minimize potential exposure to backwater from the floodway during control events. Along with accessibility by boat, the site can be reached by all-terrain vehicle or on foot via the access trail. The downstream site was selected at the downstream side of the south seepage collector channel (Figure 1). This location is far enough downstream to avoid turbulence of dam discharge during a control event. The site was selected downstream of the seepage collection channel as the possibility exists that juvenile salmonids could be found in the channel during control events. This location is accessible by boat and via a road that parallels the seepage collection channel.

Late during the 1995 field season, an alternate upstream trapping location was investigated due to the unexpectedly low capture numbers at the existing site. A site was tested downstream of the existing location (Figure 1).

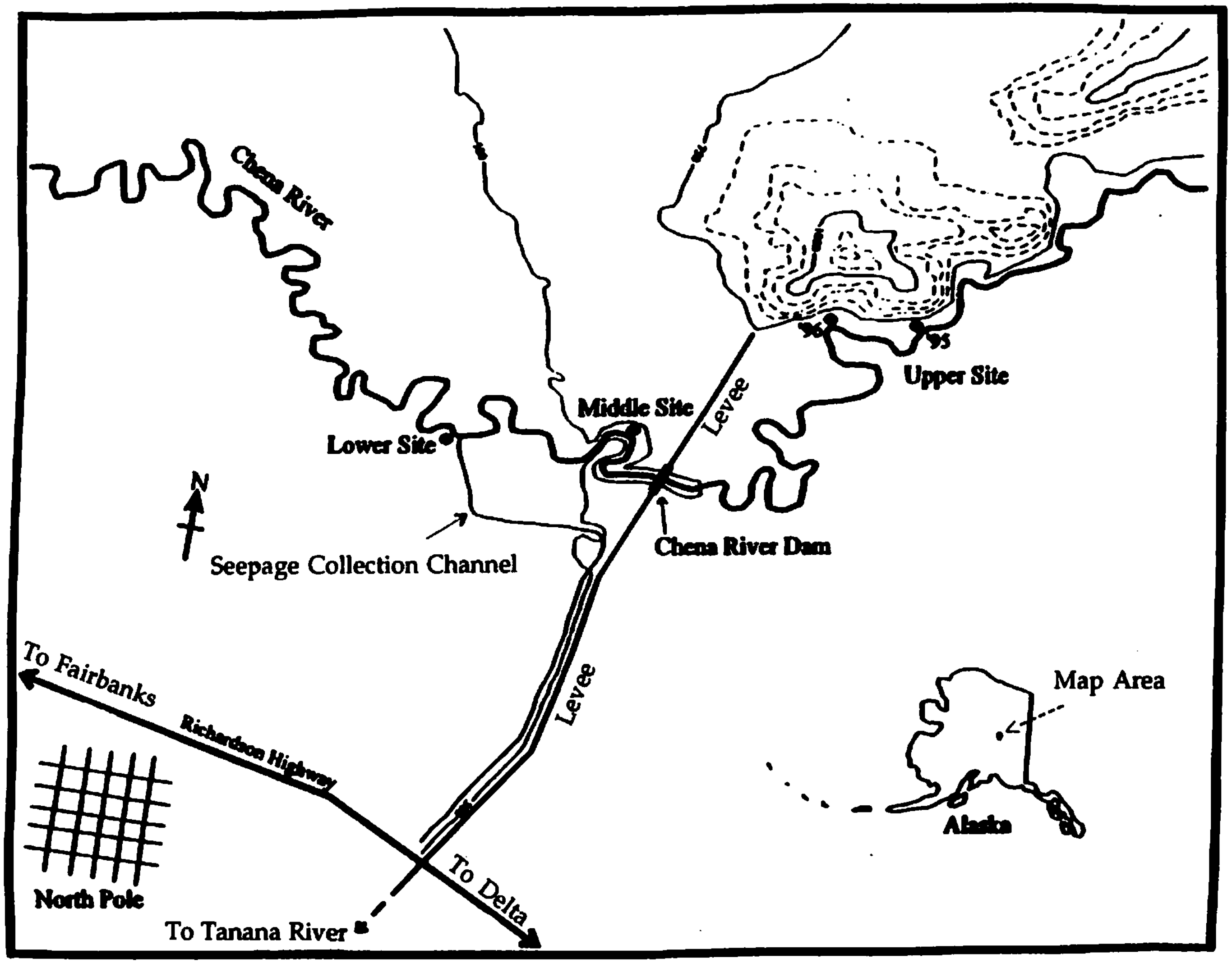



Figure 1. - Trapping site locations along the Chena River (note: map is not to scale).

The new location was along a deep cut bank just downstream of a gravel bar which forced water into a single channel along the cut bank. The site was examined during low flow conditions and proved to be an adequate trapping location. The site appeared to be an acceptable trapping location during both high and low flow conditions and was chosen as the upstream trapping location for 1996. The 1996 upstream location, like that in 1995, was accessible by boat, all-terrain vehicle, or foot. The downstream trapping location produced substantial captures of fish in 1995 and therefore remained in the same location in 1996.

A third trapping site was needed to aid a separate research project designed to investigate the movement, abundance, and survival of outmigrating juvenile salmon. Late in the 1995 field season, reconnaissance indicated that few suitable trapping locations existed downstream of the flood control dam. A middle site location was chosen between the flood control dam and the existing downstream location, just downstream of the north seepage collection channel (Figure 1). The site was located along a cut bank in a deep water channel across from a large point bar. The site was accessible by boat or via a road that paralleled the north seepage collection channel.

Field camps at each trapping site were established prior to breakup (late April-early May) and remained through the duration of field research for the season. In 1995, sampling commenced on 23 May and 22 May at the downstream and upstream trapping locations, respectively. Field sampling continued until 27 June at both locations, but capture numbers had dropped substantially prior to the termination of sampling. In 1996, sampling began on 6 May, 8 May, and 6 May at the lower, middle, and upper trapping locations, respectively. Sampling concluded on 10 June at all trapping locations due to considerable declines in capture numbers.

## Trapping Equipment

Rotary screw traps (manufactured by E.G. Solutions of Portland, Oregon) were selected as the primary means of capturing emigrating juvenile salmonids (Figure 2). Rotary screw traps have been used in glacial (Thedinga et al. 1994) and coastal rivers of Alaska (T. Bendock, Alaska Department of Fish and Game, Soldotna, personal communication) with success, but have not been used extensively on meandering interior rivers like the Chena. However, there was no reason to believe that rotary screw traps would not be a successful means of capturing juvenile salmonids on the Chena River.

During 1995, baited minnow traps were used in an attempt to increase capture numbers at each site. However, their use was abandoned due to low capture success. Beach seining operations were instituted in 1995 at the upper site to increase capture numbers. However, beach seining did not begin until late in the field season and was successful in capturing primarily age-0 chinook salmon in slack water on the Chena River. In 1996, a modified incline plane trap (Todd 1994) was the exclusive means of capture at the middle trapping location. Rotary screw traps remained in use at the upper and lower sites; no other trapping method was used in 1996.

## Purpose of Study

The goal of this study was to evaluate the effects, if any, of the Chena River Dam on the condition and health of juvenile salmonids in the Chena

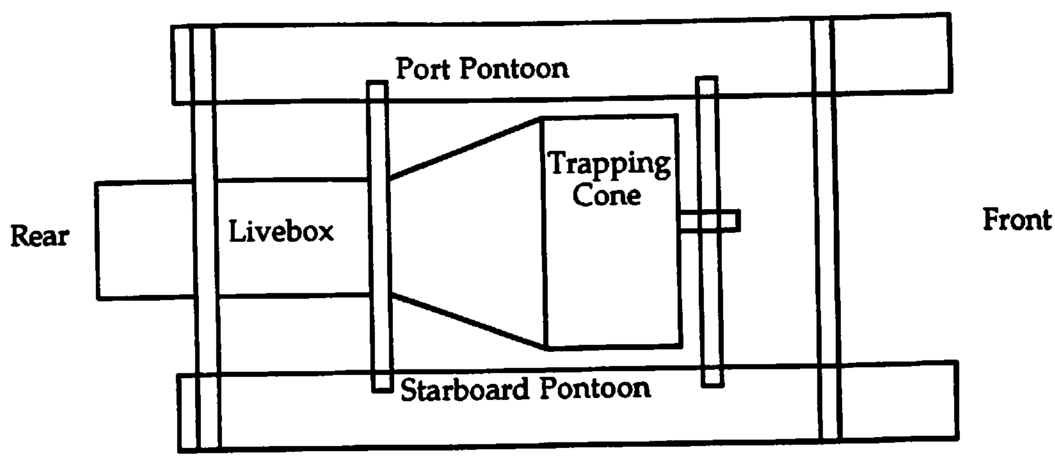



Figure 2. - Diagram of rotary screw trap.

River. Hence, the null hypothesis of this study is that no difference exists in the health and condition of outmigrants between control event and non-event years. A control event did not occur during the 1995 and 1996 outmigrations. Therefore, comparisons were made among trapping locations to determine if site differences existed in the health and condition of juvenile salmonids during 1995 and 1996. Three main objectives were pursued: document fish health through analyses of injury and scale loss; assess the vulnerability of outmigrants to predation by Arctic grayling (*Thymallus arcticus*); and identify the physiological condition of juveniles through blood chemistry analyses.

# Chapter 1

# Assessment of Fish Health through the Investigation of Injury and Scale Loss

## Introduction

The skin of teleost fishes serves diverse functions, including protection from pathogens, lubrication for swimming efficiency, and maintenance of homeostasis and osmotic integrity (Van Oosten 1957, Pickering and Macey 1977, Gadomski et al. 1994). Damage to the skin, scale, and slime complex of a fish may cause osmotic dysfunction or even death (Black and Tredwell 1967, Bouck and Smith 1979, Kostecki et al. 1987, Gadomski et al. 1994). Gadomski et al. (1994) and Kostecki et al. (1987) noted that outmigrating juvenile salmonids can encounter scale loss while passing through turbines, spillways, and bypasses of hydroelectric dams on the Columbia River. Physiological stress responses associated with descaling could affect survival by depressing immune competence and predisposing fish to disease (Peters et al. 1988, Maule et al. 1989, Gadomski et al. 1994), or by altering aspects of performance, such as the ability to avoid predation (Sigismondi and Weber 1988, Olla and Davis 1989).

Two methods have been used to investigate descaling of juvenile salmonids on the Columbia River (Gessel et al. 1991, Ceballos et al. 1993). The descaling criteria used by Ceballos et al. (1993) have been modified through years of testing by the Fish Transportation Oversight Team, a division of the National Oceanic and Atmospheric Administration. These criteria also include a classification of injuries and have proven to be the most duplicatable method, thereby minimizing observer bias (P. Wagner, Bonneville Power Administration, McNary Dam, personal communication). Therefore, the descaling criteria developed by Ceballos et al. (1993) were used to document the amount of descaling and injury of juvenile salmonids both upstream and downstream of the Chena River Dam.

On the Columbia River, Ceballos et al. (1993) documented an annual descaling incidence in chinook salmon smolts of 2.3-15.5% with a mean of 4.7 at Lower Granite Dam between 1981 and 1992. At McNary Dam between 1982 and 1992 descaling incidence for age-1 chinook salmon was 5.5-17.9% with a mean of 9.4. The Chena River Dam is a flood control system and is not equipped with turbines or other hydroelectric equipment. Therefore, passage through the Chena River Dam is not expected to cause descaling as high as that documented on the Columbia River. However, the abrasiveness of the concrete gate of the Chena River Dam and the turbulence produced by its operation could cause injury and scale loss at a level above that normally expected in a non-event year.

Methods

Rotary screw traps were operated for 1-h intervals between 1800 and 0600 hours. At the end of each interval, the trapping cone was raised to prevent additional fish from entering the live box of the screw trap. Captured fish were forced to the rear quarter of the live box by sweeping a perforated metal sheet through the live box; this was necessary to increase the efficiency and success of netting fish from the live box. The metal sheet was fitted to the dimensions of the live box to minimize the number of captured fish missed by the sweep of the metal sheet. Fish were transferred to 19 L (5 gal) buckets and transported to shore for processing. After all fish were removed from the live box, the trapping cone was lowered to begin another trapping interval. The general handling procedure was identical with salmonids captured with the incline plane trap, but the mechanics of trap operation was different. The capture ramp of the incline plane trap was attached to the live box. The entire unit was raised and lowered by a ratchet cable system. After a trapping interval, when the capture ramp was raised, the live box was separated from the ramp by a wooden divider. Because it was possible to raise the ramp and live box to any level desirable, the live box was lifted to congregate the captured salmonids in shallow water where they were netted and transferred to 19 L (5 gal) buckets.

Fish were anesthetized in a 100 mg/L solution of tricaine methanesulfonate (MS-222). Once a fish lost equilibrium, it was measured to the nearest 1 mm and transferred to a water-filled petri dish. Water in the petri dish was kept fresh in order to keep the fish moist, minimize exposure to air, and facilitate the recovery process. With the aid of a magnifying lens, each side of the fish was visually investigated for scale loss and injury.

Scale loss on each side of the fish was estimated using the criteria of Ceballos et al. (1993). Scale loss less than 3% for that side of the fish was not recorded. If the scale loss was greater than 3%, descaling percentage was estimated and the side, location, and characteristics of the scale loss were recorded. Partial descaling was defined as cumulative scale loss of both sides of the fish between 3 and 20%. Cumulative scale loss of the entire fish greater than 20% was designated as descaled. Where applicable, scale loss locations were categorized into relative sensitive areas adapted from Bouck and Smith's (1979) research with coho salmon smolts (*O. kisutch*): area 1 - along and above the lateral line from the rear edge of the dorsal fin to the caudal peduncle; area 2 - along and above the lateral line from the front edge of the dorsal fin to the operculum; area 3 - below the lateral line from mid-belly to the caudal peduncle, excluding that portion designated area 4; area 4 - below the lateral line above the pelvic fins, in the center of the fish; area 5 - below the lateral line from mid-belly to the operculum. A sixth area (area 1/2) was added due to the large amount of injuries that occurred directly below the dorsal fin between areas 1 and 2. Bouck and Smith (1979) determined the area's sensitivity by the amount of mortality that resulted from scale loss in that area. The relative sensitivity designation of 3.0 (most sensitive) indicated that scale loss in this area produced the highest mortality. The actual amount of mortality produced from each sensitive area was not reported by Bouck and Smith (1979). The relative sensitivities were 0.5, 1.0, 1.0, 1.0, 2.5, and 3.0 for areas 1, 2, 1/2, 3, 4, and 5 respectively (Bouck and Smith 1979).

In 1995, the average lengths of descaled and non-descaled chinook salmon were determined and the *F*-test was used to determine if the means of the groups were significantly different at the $\alpha$=0.05 level (Neter et al. 1990). In 1996, the average lengths of descaled, partially descaled, and non-descaled chinook salmon were compared with a oneway ANOVA to identify if the means were significantly different at the $\alpha$=0.05 level (Glantz and Slinker 1990). The Bonferroni multiple comparison procedure was utilized to compare the average length of non-descaled chinook salmon with the average length of descaled and partially descaled chinook salmon (Glantz and Slinker 1990). Because two comparisons were performed, the experiment-wide $\alpha$ level was 0.025.

The side, location, severity, and any other distinguishing characteristics of each injury were recorded. The severity index included three designations: minor, moderate, and severe. Examples of common injuries which established these categories are: minor - single nicks or cuts that do not break the skin, small tears in a fin, or shallow indents in the shape of bite marks that do not break the skin; moderate - single cuts that break the skin, multiple minor cuts, large rips in a fin or portions of fins missing, or bite marks that break the skin; severe - single deep cuts that threaten to expose internal organs, multiple moderate cuts, deep bite marks, or fungus growth over greater than one third of the body. Injuries were also grouped into the following six categories adapted from Ceballos et al. (1993): body injuries (cuts and abrasions), fin injuries, head or eye injuries, operculum injuries, bite marks, and fungus growth. The daily injury frequencies (percent of a sample with an injury), by species, site, and year, were regressed against water velocity of water entering the trap. Significance of the regression equation slopes were determined with the *F*-test (Neter et al. 1990).

The average lengths of injured and non-injured fish groups were compared with the *F*-test at the $\alpha=0.05$ level (Neter et al. 1990).

After the descaling and injury investigation, anesthetized fish were placed in a 19 L (5 gal) bucket of fresh water. When all the captured fish for that 1-h trapping interval were examined, fish were transferred to a 68 L (18 gal) holding tank in the river. The holding tanks, located in slack water along the river bank, provided a calm, fresh water supply to promote full recovery from the anesthetic. Fish were released into slack water after 1 h or just before fish from the subsequent trapping interval were placed in the holding bin, whichever came first.

Initially, chum salmon were included in the descaling investigations. However, because chum salmon scales are not fully developed at the lengths I observed at the time of capture (Sparrow 1968, Bilton 1988), chum salmon scale loss was dropped from the investigation; chum salmon injury was not.

Fish at each trapping location were treated identically. Scale loss and injury frequencies were estimated to reveal differences, if any, among trapping sites and to provide information for future comparison with scale loss and injury in years when a control event occurred.

The injury and scale loss analysis method assumed that scale loss and injury caused by the trapping and handling procedure were identical at each trapping location. This was a safe assumption for the two sites operating rotary screw traps because the trapping method was consistent at each location. However, fish caught with a rotary screw trap cannot be directly compared to fish caught by incline plane traps because the individual trap effect on injury and scale loss is unknown.

During event years, this method would also assume that any difference in scale loss or injury observed between the upstream and downstream sites was attributable to dam passage rather than the normal migration routine between the two sites. This assumption makes sense only if there is no relation between water velocity and the occurrence of injury and scale loss (i.e. high water does not cause injury and scale loss). Also, assuming that differences in scale loss and injury during event years was ascribed to dam passage would be a safe assumption because the distance and migration time between the two sites was relatively small and therefore the likelihood of any major injury or scale loss occurring within this time frame was small.

## Results

Injury - 1995

At the upstream site, 102 of the 2,872 chum fry investigated were injured producing a 4% frequency of injury (Table 1.1). A regression relation could not be established between injury frequency and water velocity because the error terms were not normally distributed. Injury classification of the 102 injured chum fry resulted in 59 minor injuries, 32 moderate injuries, and 11 severe injuries (Figure 1.1). The chum injury types were 39 body injuries, 24 bite marks, 19 operculum injuries, 12 fins damaged, and 8 head and eye injuries (Table 1.2). There was a significant difference in the length of injured versus non-injured chum salmon (p=0.016) (Table 1.3). Only 11 chinook were captured, 6 of which were injured, resulting in a 55% injury frequency (Table 1.1). A relation between injury frequency and water velocity could not be established due to insufficient data (Table A.2). The 3 minor and 3 moderate injuries (Figure 1.1) were categorized as 3 damaged fins, 1 body injury, 1 head and eye injury, and 1 operculum injury (Table 1.2). There was no significant difference between the lengths of injured and non-injured chinook salmon (p=0.942) (Table 1.3).

Table 1.1. - Annual injury frequencies (% of fish injured) by species, year, and location. Sample sizes are included in parenthesis.

| Site | Species | 1995 | 1996 |
|---|---|---|---|
| Upper | Chum | 4<br>(n=2,872) | 3<br>(n=1,116) |
| | Chinook | 55<br>(n=11) | 6<br>(n=1,772) |
| Middle | Chum | | 2<br>(n=315) |
| | Chinook | | 4<br>(n=1,468) |
| Lower | Chum | 7<br>(n=1,202) | 5<br>(n=2,739) |
| | Chinook | 2<br>(n=135) | 5<br>(n=4,081) |

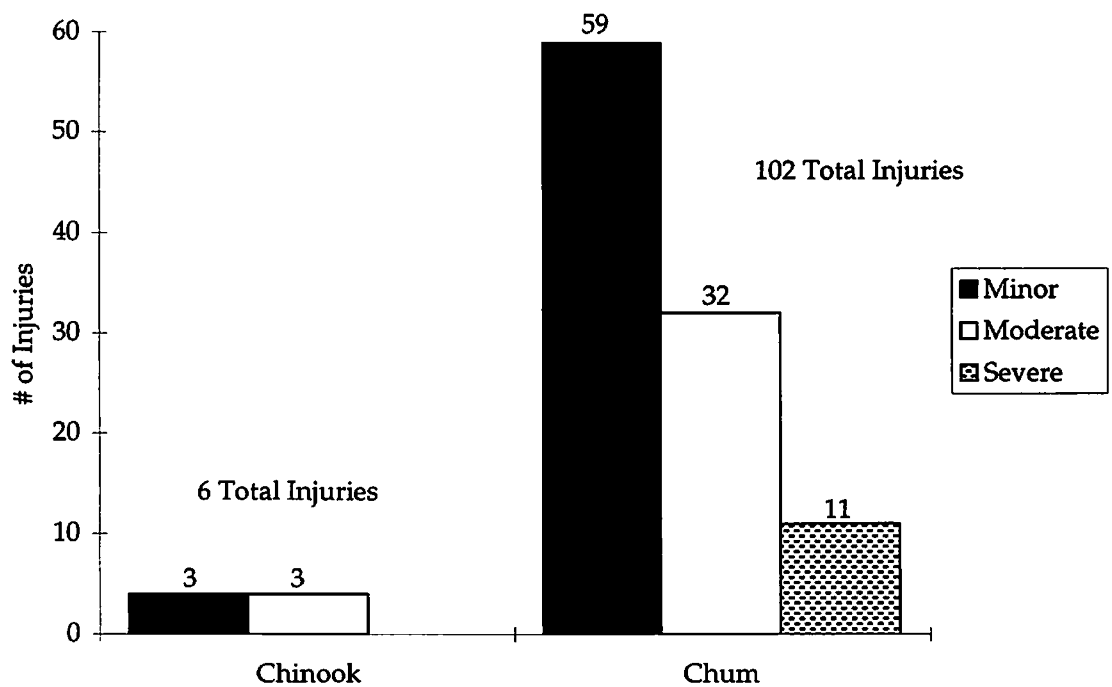



Figure 1.1. - Classification of chum and chinook salmon injuries at the upper site, 1995. Numbers at the top of the column indicate the total number of injuries in that severity designation. Chum salmon sample size = 2,872 and chinook salmon sample size = 11.

Table 1.2. - Number of injuries by category, species, and location, 1995.

| | Lower Site | | Upper Site | |
|---|---|---|---|---|
| Injury Type | Chum | Chinook | Chum | Chinook |
| Body Injury | 60 | 1 | 39 | 1 |
| Bite Marks | 9 | 1 | 24 | 0 |
| Operculum | 9 | 0 | 19 | 1 |
| Fin Damage | 2 | 0 | 12 | 3 |
| Head/Eye | 7 | 1 | 8 | 1 |
| Fungus | 1 | 0 | 0 | 0 |

Table 1.3. - Average length, injured and non-injured fish, by species and location for 1995 (standard deviations of average length are shown in parentheses). The asterisk indicates the average length of injured fish is significantly different than the average length of non-injured fish. Sample sizes are also shown in parentheses.

| Location | Species | Average Length (mm) | |
|---|---|---|---|
| | | Injured | Non-injured |
| Upstream | Chum | 44 (4) * (n=102) | 43 (4) (n=3,237) |
| | Chinook | 89 (6) (n=6) | 89 (6) (n=5) |
| Downstream | Chum | 45 (4) (n=88) | 46 (4) (n=1,114) |
| | Chinook | 85 (8) (n=2) | 85 (6) (n=119) |

At the downstream site, 88 of the 1,202 chum were injured resulting in a 7% frequency of injury (Table 1.1). The regression relation between injury frequency and water velocity was not significant (p=0.442) (Table 1.4 and Figure B.2). Of the 88 injured fish, 52 were minor, 21 were moderate, and 15 were severe (Figure 1.2). The chum injuries were described as 60 body injuries, 9 bite marks, 9 operculum injuries, 7 head or eye injuries, 2 fin damages, and 1 fungus growth (Table 1.2). No significant difference existed among the lengths of injured and non-injured chum salmon (p=0.089) (Table 1.3). Of 135 chinook, only three were injured producing a 2% frequency of injury (Table 1.1). A regression relation between injury frequency and water velocity was not established due to insufficient data (Table A.4 and Figure B.3). Injuries were classified as one minor, one moderate, and one severe (Figure 1.2). The chinook injury types were 1 body injury, 1 bite mark, 1 head and eye injury (Table 1.2). There was no significant difference in the length of injured versus non-injured chinook salmon (p=0.998) (Table 1.3).

Descaling - 1995

At the upstream site, 3 of the 11 chinook had scale loss producing a 27% descaling frequency (Table 1.5). No significant difference was observed in the average length of descaled versus non-descaled chinook salmon (p=0.917) (Table 1.6). At the downstream site, 5 of the 135 chinook salmon had scale loss producing a 4% frequency of descaling (Table 1.5). There was a significant difference in the average length of descaled versus non-descaled

Table 1.4 - Relation of the respective daily injury and descaling frequencies (% of fish injured or descaled) to water velocity (cm/s), by species and location, and year. F test for significant slope (null hypothesis: slope = 0) was conducted at the 0.05 significance level.

| Dependent Variable | Site/Year | Regression Relation | R-squared | F calculated | F critical | Significant |
|---|---|---|---|---|---|---|
| Chum Injury | Lower/95 | Y= 0.077X - 1.103 | 0.055 | 0.635 | 4.96 | No |
| Chum Injury | Lower/96 | Y = -0.029X + 8.855 | 0.004 | 0.079 | 4.35 | No |
| Chinook Injury | Lower/96 | Y = -0.253X + 36.141 | 0.086 | 2.152 | 4.35 | No |
| Chinook Descaling | Lower/96 | Y = -0.548X + 85.784 | 0.203 | 6.602 | 4.26 | Yes |
| Chum Injury | Upper/96 | Y = 0.040X + 1.791 | 0.030 | 0.220 | 5.59 | No |
| Chinook Injury | Upper/96 | Y = 0.174X + 19.681 | 0.028 | 0.737 | 4.26 | No |
| Chinook Descaling | Upper/96 | Y = 0.002X + 6.116 | 0.00007 | 0.002 | 4.35 | No |

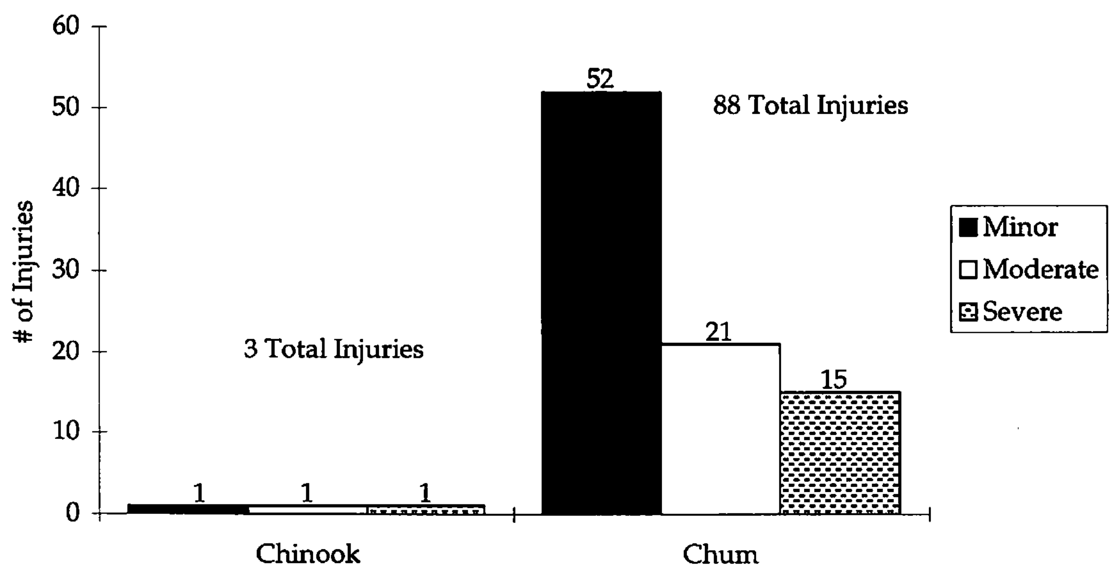



Figure 1.2. - Classification of chum and chinook salmon injuries at the lower site, 1995. Numbers at the top of the column indicate the total number of injuries in that severity designation. Chum salmon sample size = 1,202 and chinook salmon sample size = 135.

Table 1.5. - Annual chinook descaling and partial descaling (% of fish descaled or partially descaled) frequencies by year and location. Sample sizes are shown in parenthesis.

| Site | | 1995 | 1996 |
|---|---|---|---|
| Upper | Descaled | 27 (n=11) | 4 |
| | Partial Descaled | | 33 (n=1,772) |
| Middle | Descaled | | 1 |
| | Partial Descaled | | 24 (n=1,468) |
| Lower | Descaled | 4 (n=135) | 2 |
| | Partial Descaled | | 22 (n=2,790) |

Table 1.6. - Average length of descaled versus non-descaled chinook salmon by location for 1995 (standard deviations are shown in parentheses). The asterisk indicates the average length of descaled chinook is significantly different than the average length of non-descaled chinook. Sample sizes are also shown in parentheses.

| | Average Length (mm) | |
|---|---|---|
| Location | Descaled | Non-descaled |
| Downstream | 90 (8) *<br>(n=5) | 84 (6)<br>(n=130) |
| Upstream | 89 (7)<br>(n=3) | 89 (6)<br>(n=8) |

chinook salmon (p=0.023) (Table 1.6). A regression relation between descaling frequency and water velocity at either site was not established due to insufficient data (Table C.1 and Table C.2). The scale loss locations were not described in sufficient detail to be categorized into the sensitive areas of Bouck and Smith (1979).

Injury - 1996

At the upper site, 28 of 1,116 chum salmon were injured. The injury frequency was 3% (Table 1.1) and the injuries were separated into 16 minor, 5 moderate, 0 severe, and 7 mortalities (Figure 1.3). There was no significant relation between chum salmon injury frequency and water velocity (p=0.654) (Table 1.4 and Figure B.4). The chum salmon injury types were 9 operculum injuries, 6 body injuries, 4 bite marks, 1 fin damage, and 1 head and eye injury (Table 1.7). Injury types of dead fish were not assessed. There was no significant difference in the length of injured and non-injured chum salmon (p=0.564) (Table 1.8). Chinook salmon injury frequency was 6% due to 111 injuries in 1,772 captures (Table 1.1). There was no significant relation between chinook salmon injury frequency and water velocity (p=0.967) (Table 1.4 and Figure B.5). Chinook injuries were classified as 63 minor, 35 moderate, 7 severe, and 6 mortalities (Figure 1.3). The injuries were categorized as 64 body injuries, 16 fins damaged, 15 bite marks, 6 head and eye injuries, and 4 operculum injuries (Table 1.7). Injury types of dead fish were

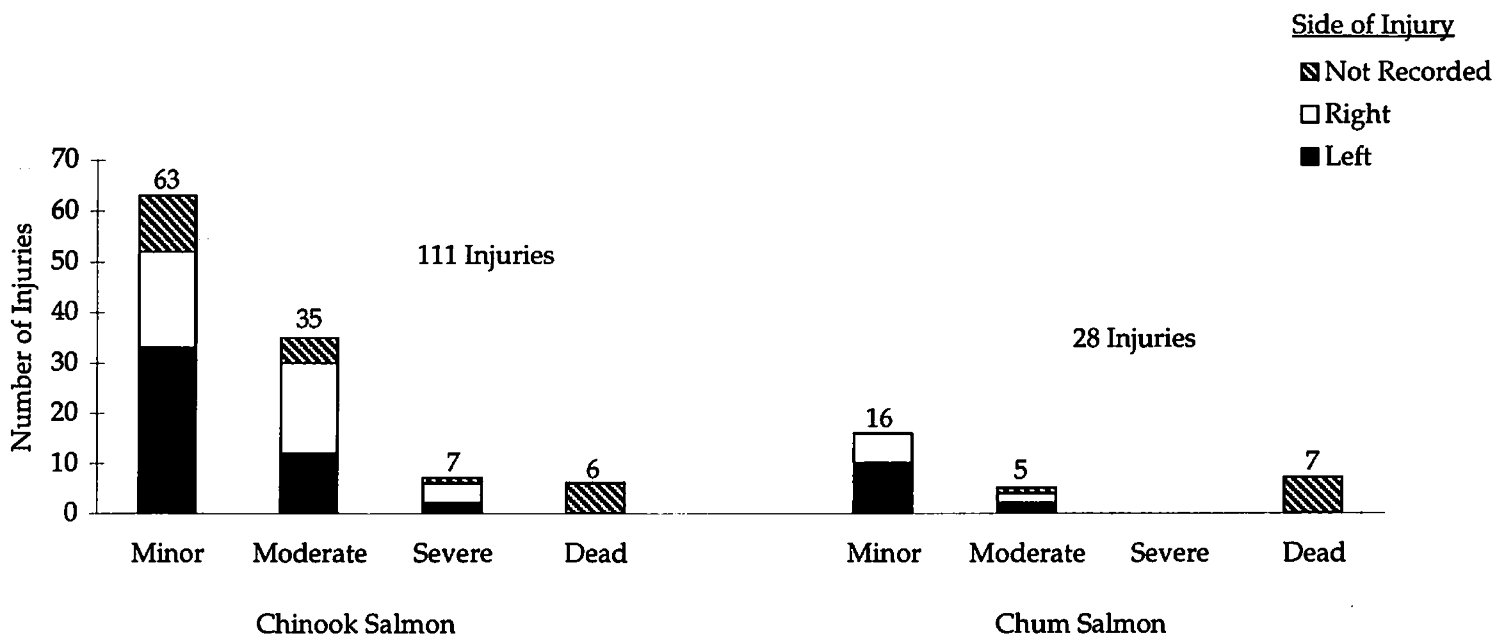



Figure 1.3. - Classification of chum and chinook salmon injuries at the upper site, 1996. Numbers at the top of the column indicate the total number of injuries in that severity designation. Chum salmon sample size = 1,116 and chinook salmon sample size = 1,772.

Table 1.7. - Number of injuries by category, species, and location, 1996.

| | Lower Site | | Middle Site | | Upper Site | |
|---|---|---|---|---|---|---|
| Injury Type | Chum | Chinook | Chum | Chinook | Chum | Chinook |
| Body Injury | 63 | 110 | 2 | 30 | 6 | 64 |
| Bite Marks | 6 | 11 | 0 | 8 | 4 | 15 |
| Operculum | 2 | 3 | 0 | 1 | 9 | 4 |
| Fin Damage | 7 | 32 | 2 | 17 | 1 | 16 |
| Head/Eye | 4 | 5 | 1 | 0 | 1 | 6 |
| Fungus | 0 | 2 | 0 | 2 | 0 | 0 |

Table 1.8. - Average length, injured and non-injured fish, by species and location for 1996 (standard deviations are shown in parentheses). The asterisk indicates the average length of injured fish is significantly different than the average length of non-injured fish. Sample sizes are also shown in parentheses.

| Location | Species | Average Length (mm) | |
|---|---|---|---|
| | | Injured | Non-injured |
| Upper | Chum | 37 (2)<br>(n=25) | 37 (3)<br>(n=1,091) |
| | Chinook | 73 (9) *<br>(n=90) | 71 (9)<br>(n=1,682) |
| Middle | Chum | 39 (4)<br>(n=5) | 39 (3)<br>(n=311) |
| | Chinook | 78 (10) *<br>(n=48) | 72 (8)<br>(n=1,420) |
| Lower | Chum | 38 (3)<br>(n=119) | 38 (3)<br>(n=2,620) |
| | Chinook | 71 (8)<br>(n=162) | 71 (8)<br>(n=3,919) |

not assessed. Injured chinook were significantly larger than non-injured chinook ($p=0.033$) (Table 1.8).

At the middle site, 5 of 315 chum salmon were injured resulting in a 2% frequency of injury (Table 1.1). The injuries were classified as 2 minor, 1 moderate, 1 severe, and 1 mortality (Figure 1.4). The injury types were 2 body injuries, 2 fins damaged, and 1 head and eye injury (Table 1.7). Injury types of dead fish were not assessed. There was no significant difference in the length of injured and non-injured chum salmon ($p=0.952$) (Table 1.8). Fifty eight of 1,468 chinook salmon were injured producing an injury frequency of 4% (Table 1.1). Injury classification was 33 minor, 20 moderate, and 5 severe (Figure 1.4). The chinook salmon injuries were characterized as 30 body injuries, 17 fins damaged, 8 bite marks, 2 fungus growths, and 1 operculum injury (Table 1.7). Injured chinook were significantly larger than non-injured chinook ($p<0.001$) (Table 1.8).

At the lower site, 129 of 2,739 chum salmon were injured with a 5% injury frequency (Table 1.1). There was no significant relation between chum salmon injury frequency and water velocity ($p=0.782$) (Table 1.4 and Figure B.6). The 129 injuries were separated into 44 minor, 20 moderate, 13 severe, and 52 mortalities (Figure 1.5). Chum salmon injury types were 59 body injuries, 7 fins damaged, 5 bite marks, 4 head and eye injuries, and 2 operculum injuries (Table 1.7). Injury types of dead fish were not assessed. There was no significant difference in the length of injured and non-injured

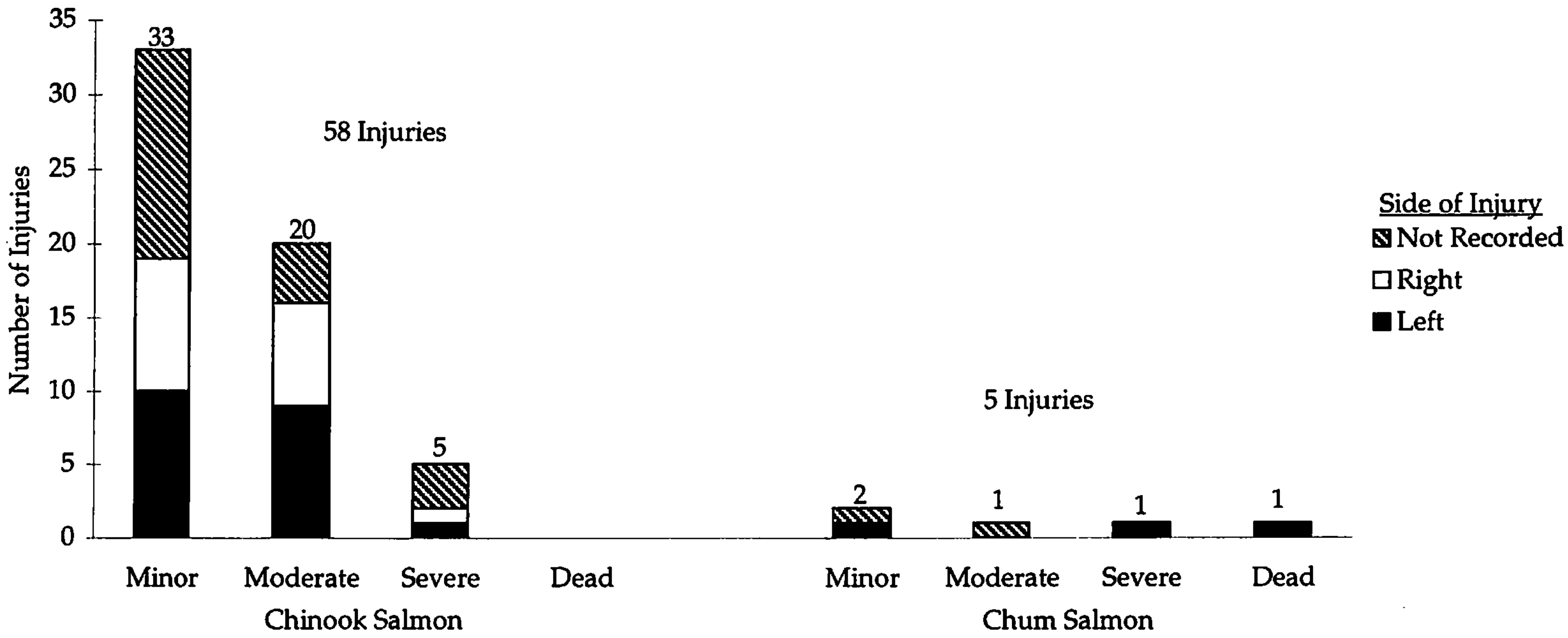



Figure 1.4. - Classification of chum and chinook salmon injuries at the middle site, 1996. Numbers at the top of the column indicate the total number of injuries in that severity designation. Chum salmon sample size = 315 and chinook salmon sample size = 1,468.

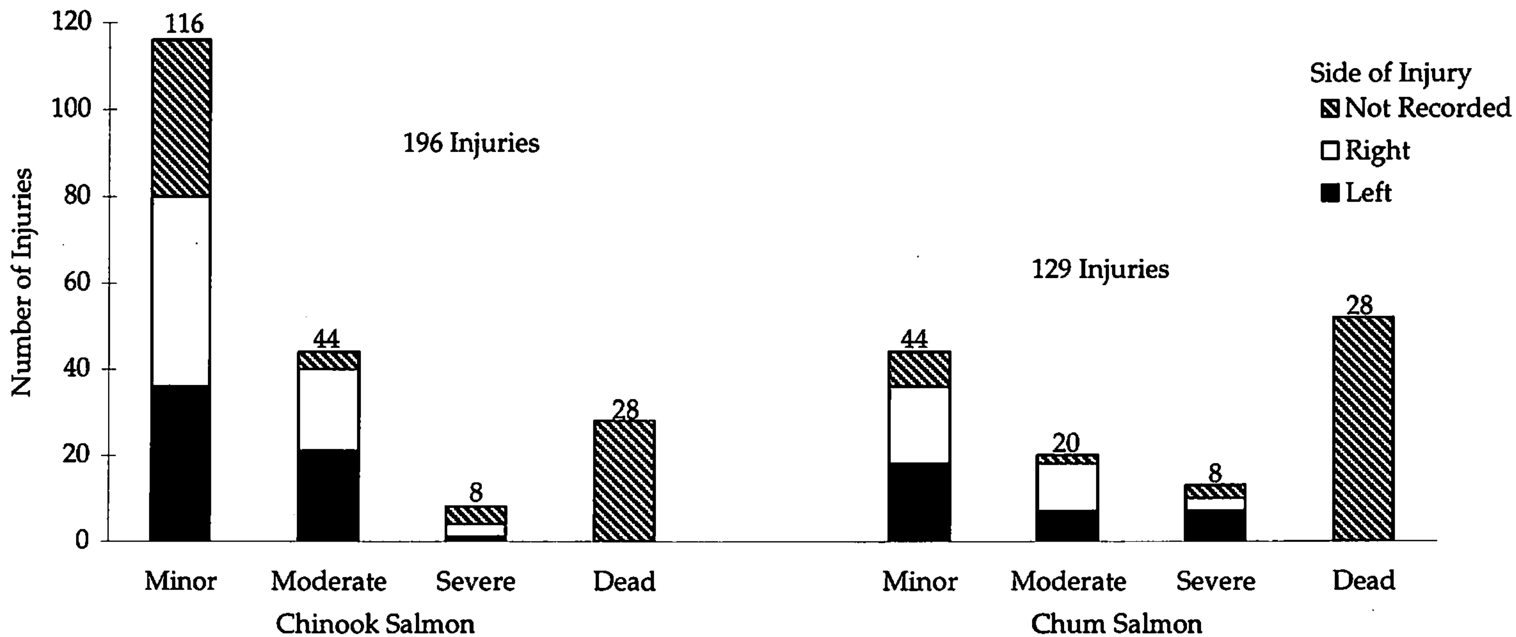



Figure 1.5. - Classification of chum and chinook salmon injuries at the lower site, 1996. Numbers at the top of the column indicate the total number of injuries in that severity designation. Chum salmon sample size = 2,739 and chinook salmon sample size = 4,081.

chum salmon ($p=0.885$) (Table 1.8). Of 4,081 chinook salmon, 196 were injured resulting in a 5% frequency of injury (Table 1.1). There was no significant relation between chinook salmon injury frequency and water velocity ($p=0.156$) (Table 1.4 and Figure B.7). The injuries were classified as 116 minor, 44 moderate, 8 severe, and 28 mortalities (Figure 1.5). Chinook salmon injury categories were 112 body injuries, 34 fins damaged, 11 bite marks, 5 head and eye injuries, 4 operculum injuries, and 2 fungus growths (Table 1.7). Injury types of dead fish were not assessed. There was no significant difference among the lengths of injured versus non-injured chinook salmon ($p=0.477$) (Table 1.8).

Descaling - 1996

At the upper site, 1,772 chinook salmon were sampled and 77 were descaled while 584 showed partial descaling. Therefore, the descaling and partial descaling frequencies were 4% and 33%, respectively (Table 1.5). The average lengths of descaled, partially descaled, and non-descaled groups of chinook salmon were significantly different ($p<0.001$). Partially descaled chinook salmon were significantly larger than non-descaled chinook ($p<0.001$) (Table 1.9). However, the average length of descaled chinook salmon was not significantly different than the average length of non-descaled chinook salmon ($p=0.047$) (Table 1.9). There was no significant relation between chinook salmon descaling frequency and water velocity ($p=0.398$) (Table 1.4 and Figure B.8). The scale loss locations were categorized

Table 1.9. - Average length of descaled, partially descaled, and non-descaled chinook salmon by location for 1996 (standard deviations are shown in parentheses). The asterisk indicates the average length of either descaled chinook or partially descaled chinook is significantly different than the average length of non-descaled chinook. Sample sizes are also shown in parentheses.

| Location | Average Length (mm) | | |
|---|---|---|---|
| | Descaled | Partial Descaled | Non-descaled |
| Upper | 72 (9) (n=78) | 74 (9) * (n=583) | 70 (8) (n=1,111) |
| Middle | 81 (10) * (n=19) | 77 (9) * (n=356) | 71 (8) (n=1,093) |
| Lower | 77 (9) * (n=44) | 75 (9) * (n=620) | 69 (7) (n=2,126) |

as 11% in area 1, 15% in area 2, 50% in area 1-2, <1% in area 3, 1% in area 4, 3% in area 5, and 20% described as diffuse (Figure 1.6).

At the middle site, 19 of 1,468 chinook salmon were descaled while 356 displayed partial descaling, resulting in descaling and partial descaling frequencies of 1% and 24%, respectively (Table 1.5). Descaled and partially descaled chinook salmon were significantly larger than non-descaled chinook salmon ($p<0.001$ in both comparisons) (Table 1.9). Scale loss locations were designated as 1% in area 1, 2% in area 2, 13% in area 1-2, <1% in area 3, <1% in area 4, <1% in area 5, and 83% characterized as diffuse (Figure 1.7).

At the lower site, 44 of 2,790 chinook salmon were descaled and 620 exhibited partial descaling. The respective frequencies of descaling and partial descaling were 2% and 22% at the lower site (Table 1.5). Descaled and partially descaled chinook salmon were significantly larger than non-descaled chinook ($p<0.001$ in both comparisons) (Table 1.9). A significant relation was found between chinook salmon descaling and water velocity ($p=0.016$) (Table 1.4 and Figure B.9). However, water velocity only explained 20% of the variability in chinook salmon descaling frequency (Table 1.4). The scale loss area designations were 4% in area 1, 2% in area 2, 24% in area 1-2, <1% in area 3, <1% in area 4, <1% in area 5, and 68% identified as diffuse (Figure 1.8).

Water velocity of water entering the trap does not appear to have a significant effect on the frequency of injury or scale loss, regardless of species or location (Table 1.4). The relation between water velocity and injury or

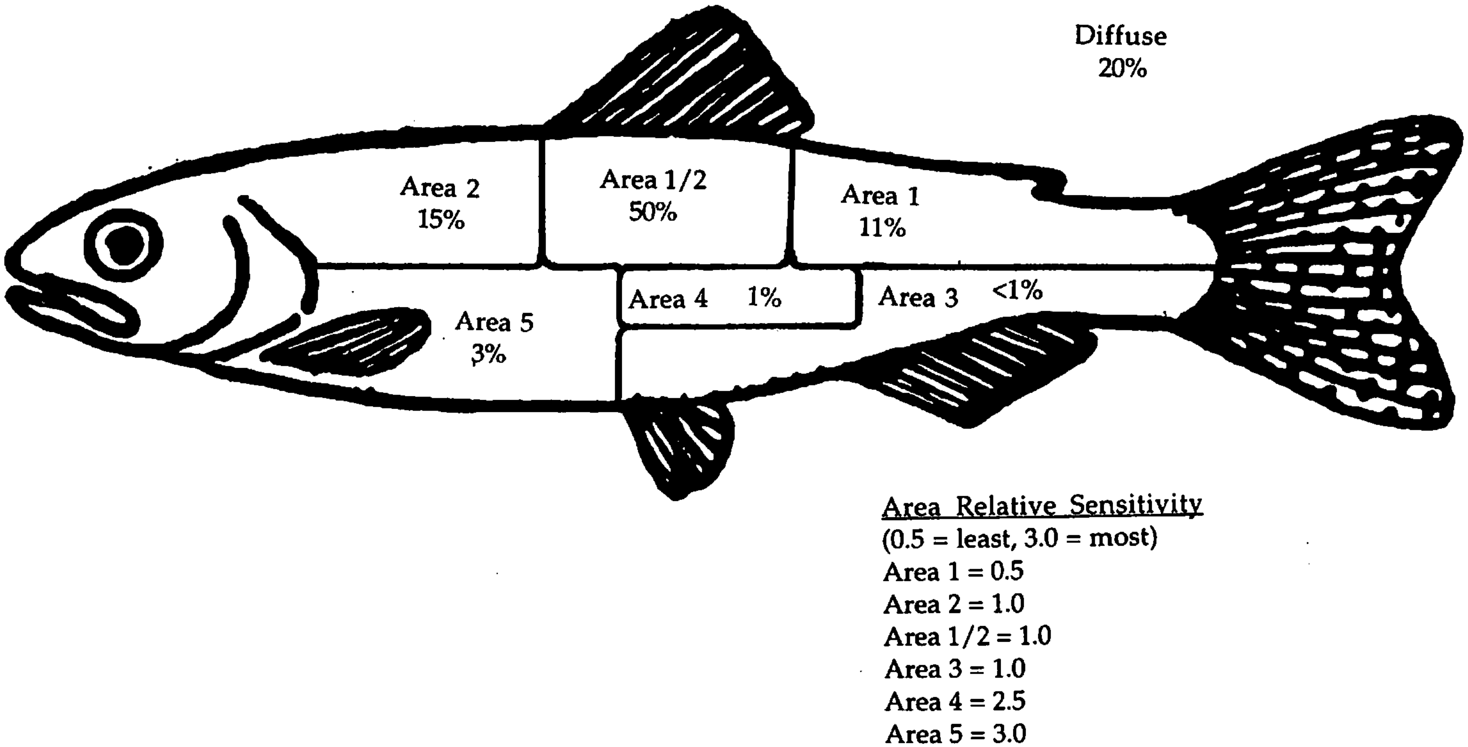
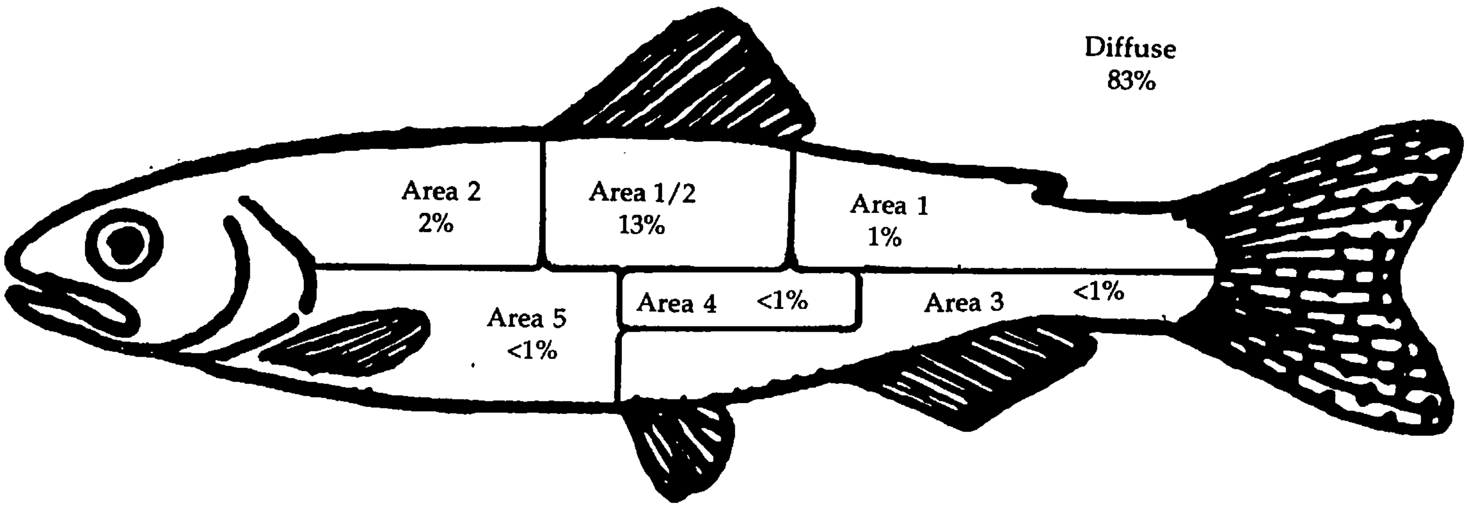
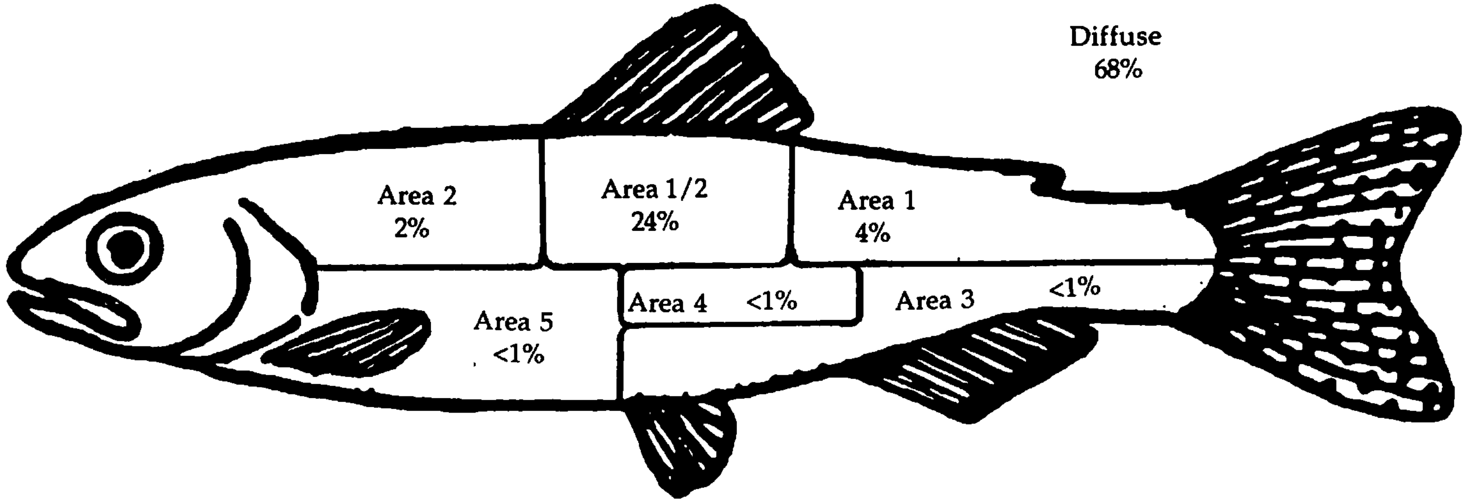



**Figure 1.6.** - The percentage of chinook salmon scale loss at the upper site recorded in each of the sensitive areas, 1996 (adapted from Bouck and Smith 1979).




<u>Area Relative Sensitivity</u>
(0.5 = least, 3.0 = most)
Area 1 = 0.5
Area 2 = 1.0
Area 1/2 = 1.0
Area 3 = 1.0
Area 4 = 2.5
Area 5 = 3.0

**Figure 1.7. - The percentage of chinook salmon scale loss at the middle site recorded in each of the sensitive areas, 1996 (adapted from Bouck and Smith 1979).**




<u>Area Relative Sensitivity</u>
(0.5 = least, 3.0 = most)
Area 1 = 0.5
Area 2 = 1.0
Area 1/2 = 1.0
Area 3 = 1.0
Area 4 = 2.5
Area 5 = 3.0

**Figure 1.8. - The percentage of chinook salmon scale loss at the lower site recorded in each of the sensitive areas, 1996 (adapted from Bouck and Smith 1979).**

scale loss frequency was investigated over water velocities ranging from 45-130 cm/s. The 45 cm/s was recorded in 1995 during a period of extremely low water (D. Dahl, U.S. Army Corp of Engineers, North Pole, AK, personal communication). The 130 cm/s is similar to water velocities obtained during a short flood event late in the 1995 field season.

## Discussion

Because both years of this study were non-event years, the reported injury and descaling frequencies are considered baseline information. These data could be utilized in future years as a comparison with fish that have experienced a flood-control event.

Except for the 55% frequency of injury for chinook salmon at the upper trapping location in 1995, all injury frequencies were 7% or less, regardless of the species or location. In addition, over half (54%) of the total injuries were classified as minor while very few were severe (8%). Therefore, due to the low injury frequency and the large proportion of minor injuries, chinook and chum salmon appear to be in good condition while outmigrating from the Chena River.

The three most common injury types were bodily injury, fin damage, and bite marks, respectively. This is different than the injury types recorded on the Columbia River where avian predators and fungus growth appear to be the two largest sources of injury (Ceballos et al. 1993). The size and habitat of the Columbia appears to be conducive to the survival of fish-eating birds such as birds in the family Laridae (gulls, terns)(personal observation). The prevalence of fungus growth is likely due to the presence of numerous hatcheries supplementing salmonid stocks throughout the Columbia River. Neither of these two conditions exist on the Chena River which probably explains the difference in injuries observed in the two systems.

The frequency of chinook salmon scale loss (both descaling and partial descaling) ranged from 1-33%. In 1996, scale loss designations were divided into descaled and partially descaled fish. The frequency of descaled fish (i.e. ≥ cumulative scale loss of 20%) ranged from 1-4%. The partial descaling frequency (i.e. scale loss between 3-20%) ranged from 22-33%. The descaling frequencies are similar to those recorded on the Columbia River for chinook salmon and steelhead trout (*O. mykiss*) (Ceballos et al. 1991, 1993). Although Gessel et al. (1991) reported higher descaling percentages at the Bonneville Dam, Columbia River, the descaling was attributed to experimental operation of fish guidance systems and submersible traveling screens. Koski et al. (1990) noted that the percentage of juvenile salmonids that are descaled at Columbia River dams varies widely depending on location, season, year, and species. Because most of the scale loss in my study was recorded as partial descaling and the majority of the partial descaling was in the low end of the partial descaling range (i.e. 3-10%), chinook salmon on the Chena River appear to be in good condition. In addition, salmon smolts are able to regenerate scales

(Bouck and Smith 1979, Hayes 1987). Hayes (1987) showed that substantial scale regeneration occurs after 10 days and complete scale regeneration can occur in 21 days. Hayes (1987) also demonstrated that the scale regeneration process appears to be faster in smolts with a higher degree of scale loss. Bouck and Smith (1979) demonstrated different reactions of experimentally descaled coho salmon smolts to fresh and salt water challenge tests: no fish died in the fresh water challenge test but an average of 75% of the fish died during the first 10 days of exposure to seawater. However, seawater tolerance was soon restored if the fish were allowed to remain in fresh water for just a few days (Bouck and Smith 1979). Chena River salmonids have ample time to regenerate scales before exposure to seawater. Gadomski et al. (1994) suggest that descaling of juvenile chinook salmon could result in decreased resistance to disease and other stressors in the field, possibly leading to reduced performance capacity and lowered survival. However, due to the minimal occurrence of chinook salmon descaling on the Chena River and the fish's ability to regenerate scales, descaling is not expected to affect the fish's condition, susceptibility to pathogens, or osmotic integrity.

The majority of scale loss was characterized as diffuse. The diffuse designation commonly described scale loss that was scattered along or above the lateral line. This area ranges in its sensitivity to scale loss from 0.5-1.0 (Bouck and Smith 1979), indicating that scale loss that occurs in this area will result in less mortality compared to scale loss occurring in more sensitive areas of the fish. For the scale loss locations with definite area designations, 94% were found in areas 1, 2, and 1-2 of Bouck and Smith (1979). These areas range in sensitivity from 0.5-1.0 and can be distinguished as the least sensitive areas to the effects of descaling (Bouck and Smith 1979). Kostecki et al. (1987) support Bouck and Smith's (1979) relative sensitivity indices stating that the tail and dorsal region contain large, thick muscle masses which may account for a fish's relative tolerance to scale loss in these areas. The location of descaling primarily observed on the Chena River suggests that the areas most sensitive to scale loss may be the areas least likely to lose scales. This notion was first suggested by Kostecki et al. (1987). In short, the sensitive area designations of the scale loss locations observed on the Chena River support the claim that descaling produces minimal effects on chinook salmon condition.

Fish length appears to affect susceptibility to both injury and scale loss. When a significant difference existed among the average length of injured compared to non-injured fish, injured fish were always larger. Likewise, when a significant difference was observed among the average length of either descaled or partially descaled fish compared to non-descaled fish, descaled and partially descaled fish were always larger. Therefore, larger fish appear to be more susceptible to injury and scale loss. This is consistent with information obtained on the Columbia River where length played a significant role in the susceptibility to descaling under artificial environments like the hydroelectric dams on the Columbia River (P. Wagner, Bonneville Power Administration, McNary Dam, personal communication). It is unclear whether larger juvenile salmon on the Chena River are actually more susceptible to injury and scale loss or simply that larger fish have likely lived longer and, therefore, have had more opportunity to be injured or descaled.

There seems to be no substantial differences in the injury frequencies among the three trapping locations, except for the injury frequency of chinook salmon at the upper site in 1995 and this inconsistency is most likely due to the unreliable nature of the data due to a small sample size. The similar injury frequencies imply that the sampling methods are consistent among sites, the potential sources of injury are equivalent among the sites, and the recorded injury frequencies are probably typical for chum and chinook salmon in the Chena River near the Chena River Dam. Also, the similar injury frequencies suggests that there was no trap effect on injury since different trapping methods were used.

The range of descaling and partial descaling frequencies were not as consistent among the sites as the injury frequencies. The inter-annual differences are likely due to the drastic variation in sample sizes between years. However, in both years, descaling and partial descaling frequencies were greatest at the upper trapping location, perhaps due to the high occurrence of in-stream structure, such as woody debris (a potential source of descaling), relative to the other trapping locations. In 1996, the descaling and partial descaling frequencies at the middle and lower trapping locations were extremely similar, suggesting that there was also no trap effect on descaling.

# Chapter 2

## Predation on Juvenile Salmonids by Arctic Grayling

### Introduction

At dams on the Columbia River, migrating juvenile salmon are stressed by passage through traveling screens, gatewells, fish sorters, turbines, and spillways (Matthews et al. 1986, Maule et al. 1988, Mesa 1994). The high predation rates at dams may be due in part to juvenile salmon being stressed by dam passage (Mesa 1994). Most research has indicated that prey in substandard condition are significantly more vulnerable to predation (Mesa et al. 1994).

Passage through the Chena River Dam is not expected to affect the condition of juvenile salmonids to the same magnitude documented on the Columbia River. However, juvenile salmonids are not expected to be in optimum condition after dam passage during a control event and, therefore, may be more vulnerable to predation. In addition, the dynamics of the predator-prey relationship of Arctic grayling with juvenile salmonids is likely to differ from the interaction of northern squawfish (*Ptychocheilus oregonensis*) and juvenile salmonids on the Columbia River. Therefore, the interaction of predator and prey species specific to the Chena River needs to be considered when investigating the condition of outmigrants and the impact of predators on the survival of juvenile salmonids.

An established method for examining predator-prey interactions is the analysis of predator stomach contents. This method has been used extensively on the Columbia River and an in-depth description can be found in Peterson et al. (1990, 1991), Shively et al. (1991), and Tabor et al. (1993). The method described by these authors requires the sacrifice of substantial quantities of predators. The status of the Chena River Arctic grayling stocks and the protective measures that are currently in place will not allow the sacrifice of Arctic grayling.

Seaburg (1957) developed a device that permits the removal of the entire stomach contents without injuring the fish. The stomach sampler works by forcing low pressure water into the fish's stomach and flushing the contents back out through the fish's mouth. Modified versions of the Seaburg stomach sampler have been used successfully with various species and stomach contents (Shively et al. 1991, Tabor et al. 1993, N.F. Hughes, Simon Fraser University, personal communication), and hence, appears to be the best method for obtaining stomach contents of Arctic grayling on the Chena River.

## Methods

Arctic grayling were collected by boat electrofishing and angling upstream and downstream of the Chena River Dam. Electrofishing was done in cooperation with Alaska Department of Fish and Game (ADF&G)

personnel and with the use of ADF&G equipment. Angling was performed primarily with dead drift fly fishing techniques using nymph patterns; dry flies and spinners were used to a lesser extent. Fish were collected at various times in the diel cycle and from different locations to identify potential fluctuations in Arctic grayling feeding intensity.

Immediately after capture, Arctic grayling were transferred to a recirculating water tank located on the electrofishing boat, anesthetized with MS-222, and measured (fork length) to the nearest 1 mm. Weight (grams) was determined with a Pesola brand spring loaded scale. Water temperature, time of day, weather conditions, and river location were recorded.

Stomach contents were flushed with a modified Seaburg stomach sampler onto a filter screen. The stomach contents were backflushed from the screen into a nylon stocking. Stomach contents were transferred to labeled sample bags, sealed, and stored in coolers. Arctic grayling were revived in a fresh water holding tank before being released in slack water near the point of capture.

Within 24 hours, stomach samples were transported to the lab for separation and weighing. Stomach contents were separated into five categories: juvenile chum salmon, juvenile chinook salmon, other fish species, invertebrates, and miscellaneous material. All ingested fish were identifiable by species. Juvenile salmon were enumerated to quantify the magnitude of predation. The contents of each category were patted dry with paper towels and wet weights (nearest 0.001 g) were obtained with a Mettler PM480 Delta Range balance. Stomach samples were stored in sample bags, labeled, frozen, and archived.

A meal turnover-time method was used to estimate Arctic grayling daily consumption rate of chum salmon (Diana 1979). First, daily ration was calculated using the equation:

$$R = \frac{M \times n}{ET90 \times N}$$

where R = daily ration (% body weight/d), M = average size of ingested meal (% body weight) of those fish that contained food, n = number of fish that contained food, ET90 = number of days for gastric evacuation of 90% of the stomach contents, and N = total number of fish sampled. The ease with which a food item is fragmented in the stomach may be an important factor in determining evacuation patterns (Hopkins and Larson 1990). Elliot (1972) calculated the rates of gastric evacuation of invertebrate prey in brown trout. However, digestion rate equations relative to fish prey types are not available for Arctic grayling or other salmonids. Therefore, the ET90 was calculated using digestion rate equations for smallmouth bass (Rogers and Burley 1991). The ET90 equation was:

$$ET90 = 24.542 S^{0.29} e^{-0.15T} W^{-0.23}$$

where S = meal weight (g), T = temperature (°C), and W = predator weight (g). Consumption rate was determined using the equation:

$$C = \frac{R \times P \times \text{mean predator weight (g)}}{\text{mean individual salmonid prey weight (g)}}$$

where C = consumption rate (number of salmonids consumed per predator daily), R = daily ration, and P = proportion of the diet by weight that is salmonid prey. Mean salmonid prey weight was a constant, 0.4 g, and represented the original weight of individual salmonid prey before ingestion. This constant was the mean weight of individual fish in samples of similar length chum salmon taken from Sparrow (1968) and Merritt and Raymond (1983). I assumed that the length-weight relation of Chena River age-0 chum salmon was the same as that observed by these authors. The meal turnover-time method assumed that feeding by the population is asynchronous and that a sample of predators taken at any time would include prey representative of all levels of feeding (Adams and Breck 1990). Arctic grayling abundance estimates on the Chena River (Clark 1996) along with the salmonid consumption rate for Arctic grayling were used to estimate the magnitude of predation on chum salmon by Arctic grayling in the Chena River system.

I assumed that salmonids will be in sub-standard condition after dam passage during a control event; that Arctic grayling are capable of identifying prey in a sub-standard condition; and that these predators preferred to feed upon the more vulnerable prey. Previous research in predator-prey interactions indicated these were safe assumptions (Mesa 1994). Also, the

Seaburg stomach sampler was assumed to be effective in retrieving total gut contents. The effectiveness of the Seaburg sampler could not to be tested due to the no-harvest policy on Arctic grayling in the Chena River, but previous research documents the effectiveness of this device (Shively et al. 1991, Tabor et al. 1993, N.F. Hughes, Simon Fraser University, personal communication). Unpublished data from U.S. Fish and Wildlife Service research performed in 1981-1983 indicated that juvenile salmonids found in the gut contents of Arctic grayling were easily identifiable. In addition, I assumed that the various factors that could affect feeding dynamics (i.e. water velocity, visual clarity, depth, predator and prey density) will remain fairly constant between the sampling locations upstream and downstream of the dam. The close proximity of the sampling sites and the similarity of habitats among sample locations suggested this was a safe assumption.

## Results

### 1995

Of 99 Arctic grayling examined, only 7 had ingested a total of 31 chum salmon. Above the dam, the diet by weight consisted of 93% invertebrates, 4% chum salmon, and 3% miscellaneous material (Figure 2.1). Below the dam, the diet by weight was 98% invertebrates, 1% fish other than chinook or chum salmon, and 1% miscellaneous material (Figure 2.1). Invertebrates

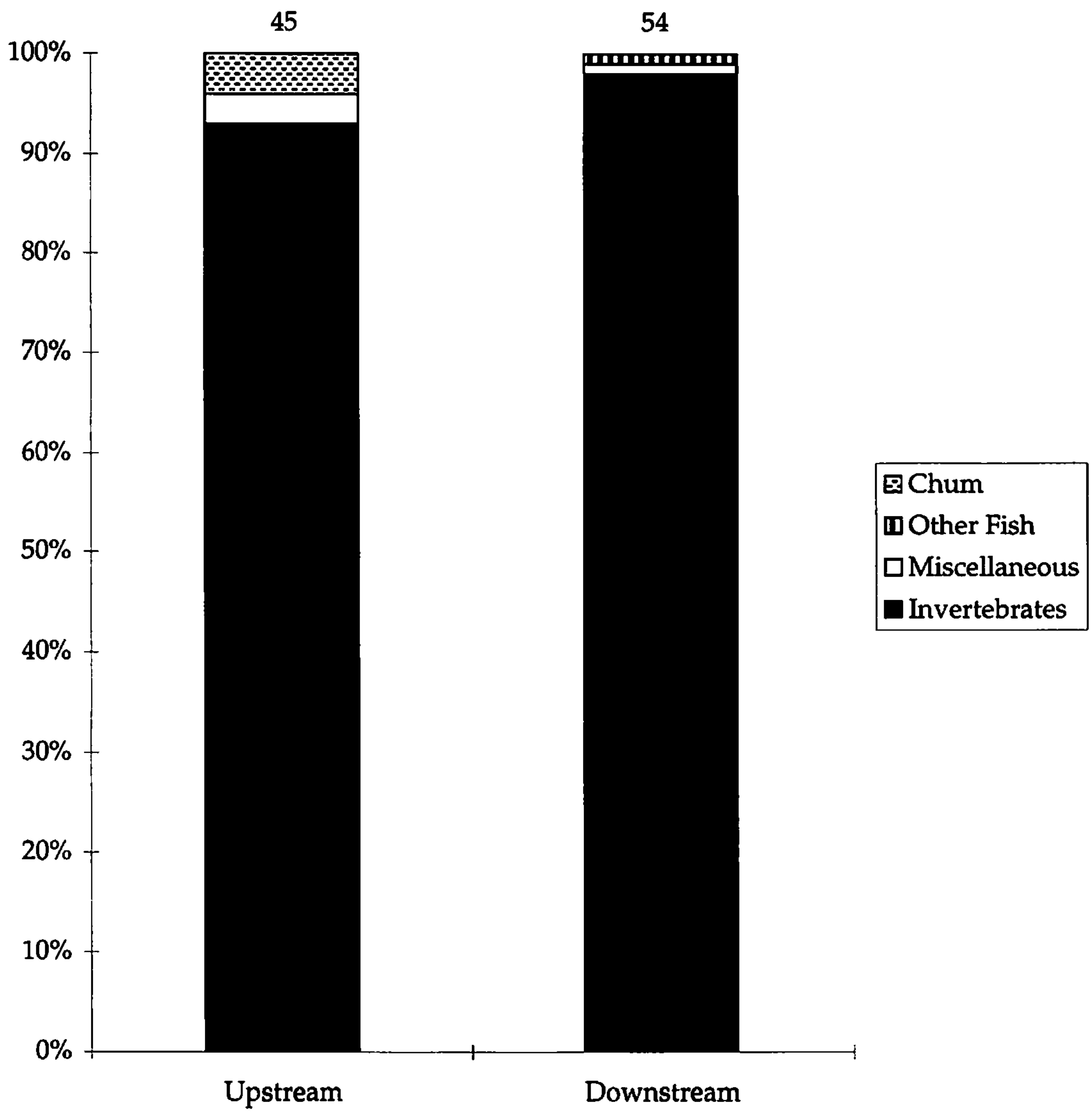



Figure 2.1. - Composition (percent by weight) of ingested food items of Arctic grayling near the Chena River Dam, 1995. Number of predators sampled are shown at the top of the column.

were found in all of the 99 Arctic grayling sampled. No chinook salmon were found in Arctic grayling stomachs.

1996

Eight of 80 Arctic grayling ingested a total of 9 chum salmon. Arctic grayling diet above the dam contained 92% invertebrates, 4% miscellaneous material, 3% other fish, and 1% chum salmon by weight (Figure 2.2). Below the dam, Arctic grayling diet by weight was comprised of 88% invertebrates, 8% fish other than chinook or chum salmon, and 4% miscellaneous material (Figure 2.2). All of the Arctic grayling sampled had eaten invertebrates; none had eaten chinook salmon.

Consumption Rate

Arctic grayling consumed a daily average of 0.03 chum salmon. The 1995 abundance estimate of Arctic grayling (≥150 mm FL) in the lower 152 km of the Chena River was 49,454 fish (Clark 1996). Therefore, over a 30-day outmigration period, Arctic grayling consumed an estimated 44,509 chum salmon.

## Discussion

The diet of Arctic grayling near the Chena River Dam is dominated by invertebrates. This is consistent with Armstrong (1986) who stated that larval and adult aquatic insects are the major food of Arctic grayling in Alaska. Although juvenile chum salmon may be a highly nutritional food source,

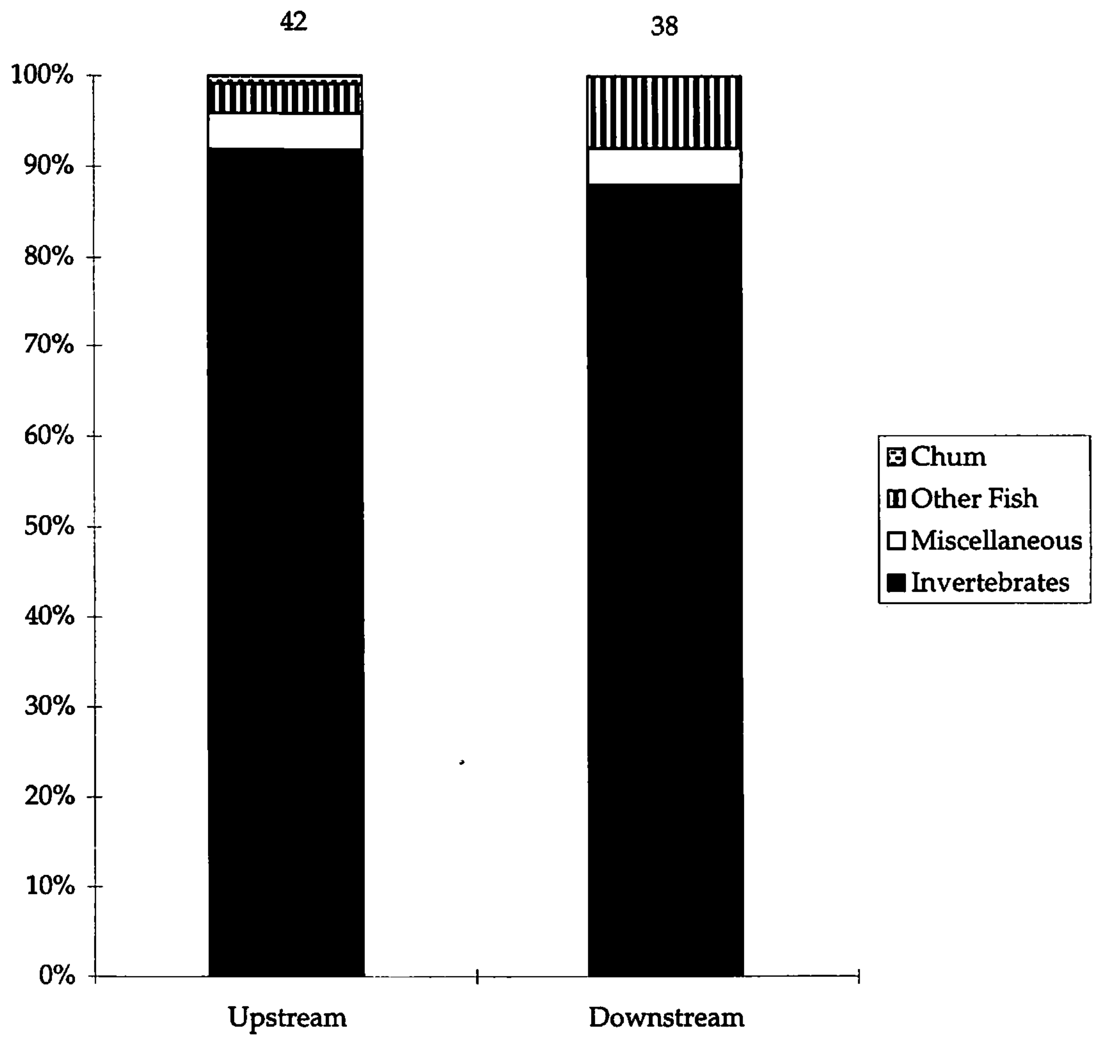



Figure 2.2. - Composition (percent by weight) of ingested food items of Arctic grayling near the Chena River Dam, 1996. Number of predators sampled are shown at the top of the column.

they do not appear to be an important component of the Arctic grayling diet. Arctic grayling are known to be opportunistic feeders that will feed continuously without becoming satiated (Hughes and Dill 1990). The Arctic grayling diet composition suggests that invertebrates are more easily ingested than chum salmon, perhaps due to a greater density, higher frequency of encounter, or lack of a flight response. Hughes (1992) stated that the number of prey a fish sees increases with water depth, water velocity, and the density of prey in the water. Also, the proportion of prey that the fish is able to capture declines with increasing water velocity, while the predator's swimming costs increase with water velocity (Hughes and Dill 1990, Hughes 1992). The fish must select a position where the combination of these factors maximizes its net energy intake (Hughes 1992).

On the Chena River, grayling were observed feeding in areas close to but not within the thalweg. These feeding positions could be characterized by intermediate water velocity and depth relative to the remainder of the river, a definite trade-off in the number of prey the fish can detect and the proportion of those prey detected that the fish can capture. These feeding locations may explain the limited amount of predation on juvenile chum salmon. During the day, chum salmon are primarily found holding and feeding in the slack water along the stream bank (Hoar 1958, Kostarev 1970, Salo 1991, personal observation). They move into the thalweg at night during their downstream migration (Neave 1955, Hoar 1958, McDonald 1960, Godin

1981), a time when it is difficult for Arctic grayling to detect their movement. Therefore, the feeding position of Arctic grayling does not seem to overlap with the preferred habitat of emigrating chum salmon. The notion that habitat choice affects the predator-prey relationship is supported by Gray and Rondorf (1986) and Tabor et al. (1993) who stated that the potential for predation upon juvenile salmonids is high when the predator and prey are spatially synchronous. In summary, during non-event years, predation by Arctic grayling does not appear to have a substantial effect on chum salmon abundance near the Chena River Dam.

I estimated that Arctic grayling consume 44,509 chum salmon over the course of a 30-day outmigration period. This is a substantial portion of the estimated 1996 Chena River chum salmon population size of 266,104 (95% C.I. - 128,031-404,177) (Peterson, 1996). This is likely an overestimation of grayling consumption of chum salmon. The Chena River Arctic grayling abundance estimate used to estimate total chum salmon consumption was obtained during July, after Arctic grayling have taken residence in their summer feeding areas (Armstrong 1986). In May, there are probably fewer Arctic grayling within the mainstem Chena River because some fish may still be migrating into the Chena River from overwintering habitats outside the mainstem Chena (Armstrong 1986). Also, grayling are migrating to spawning areas and may feed less due to their focus on the spawning season. The method behind this estimate assumes that chum salmon are available to

Arctic grayling throughout the entire lower 152 km of the Chena River during every day of the outmigration. This assumption is violated for a number of reasons. First, some chum salmon fry emerge well below the 152 km delineation for the Arctic grayling abundance estimate and therefore are never available to predators upstream of the point of emergence. Second, chum salmon appear to move downstream at a relatively slow rate and thus would not be available to Arctic grayling in the lowest reaches of the Chena during the early part of the outmigration. Third, once chum salmon have passed a particular point in the river, they are no longer available to predators above that point in the river.

All predation on juvenile chum salmon occurred in mid to late May and no predation was observed after 31 May in either year. This time period coincides with the time of peak or near-peak chum salmon migration near the Chena River Dam (Williamson 1984, Peterson 1996). This is consistent with recent research on the Columbia River where predator consumption rates were highest during the peak period of salmonid outmigration (Poe et al. 1991, Rieman et al. 1991, Vigg et al. 1991, Tabor et al. 1993). Therefore, the observation that Arctic grayling consumption of emigrating chum salmon was highest during the time of peak migration is consistent with predation research on other predators and in vastly different systems.

Most chum salmon were ingested by fish captured upstream of the dam. This may be due to slight habitat differences in the river upstream and downstream of the Chena River Dam. The upper river has not been affected by water regulation due to dam operation. Thus, this portion of river has been subjected to the annual scouring events that occur during ice-out and spring runoff that are typical of subarctic rivers. The upper river has a defined pool:riffle sequence, substantial in-stream and overhanging cover, and definite slack water pools and side channels. Chum salmon have been observed actively swimming in riffle areas to increase the speed of their downstream migration (Neave 1955, Salo 1991, Massa 1995) and holding in slack water pools during the day to avoid predation (Neave 1955, Hoar 1958, McDonald 1960, Godin 1981). Chena River chum salmon appear to follow this pattern in the upper river where the habitat is available. Hence, they are congregated in pools and may be susceptible to predation by Arctic grayling throughout the day.

Downstream from the Chena River Dam, the river differs from upstream primarily due to the lack of a consistent pool:riffle sequence. Although the chum salmon continue the pattern of actively migrating at night and holding during the day, there are fewer defined pools in which chum salmon congregate during the day. Chum salmon are forced to spread out throughout a cross section of the river, finding refuge in small shoreline slack water areas or in reduced currents behind gravel or other obstacles. By being distributed throughout a cross section of the river chum salmon decrease the rate at which they encounter Arctic grayling. Grayling choose specific positions for feeding and return to that position after capturing a prey item (Hughes and Dill 1990). Therefore, predation would be reduced because predator and prey are spatially asynchronous (Gray and Rondorf 1986, Tabor et al. 1993).

No chinook salmon were ingested by Arctic grayling. A number of plausible explanations exist. First, the swimming capabilities of juvenile chinook salmon may be sufficient to cause grayling to expend a substantial amount of energy, making the net energy gain from ingesting a chinook salmon extremely minimal. The simplest way for a predator to maximize the net energy gain is by minimizing the energetic costs of capturing its prey (Wootton 1990). Thus, Arctic grayling may choose not to pursue chinook salmon as prey if too much energy is expended in the chase and if other suitable food exists. Second, juvenile chinook salmon may be an unsuitable size food for Arctic grayling in the Chena River. Handling time is a component of the energetic costs of capturing a prey item and can increase as the size of the prey item increases (Wootton 1990). Therefore, if juvenile chinook salmon are of sufficient size to increase Arctic grayling handling time, grayling may not attempt to capture chinook salmon. The dominant food source of Arctic grayling in the Chena River is invertebrates. It is doubtful that invertebrates are a more nutritional food than chinook salmon in a direct comparison of energy per unit weight. However, the energetic benefits of ingesting a prey item depend both on the nutritional value of the prey item and the energetic cost of capturing that item. To an Arctic grayling, the energetic cost of capturing a juvenile chinook salmon may make other prey items more energetically beneficial.

# Chapter 3

# Primary Stress Response of Juvenile Chinook Salmon to Capture and Handling Stress

## Introduction

Cortisol secretion is a well known primary response to stress in fish. Cortisol probably mediates immune suppression that may occur during prolonged or severe stress (Wendelaar Bonga 1993). Also, cortisol probably inhibits growth and reproduction during prolonged or severe stress (Wendelaar Bonga 1993). Numerous studies with salmonids have focused on the changes in plasma cortisol in response to various types of stressors (Schreck and Lorz 1978, Strange et al. 1978, Redding et al. 1984, Barton et al. 1985, Barton et al. 1986, Barton and Schreck 1987, Maule et al. 1988, Schreck et al. 1989, Avella et al. 1991, Pottinger et al. 1992, Salonius and Iwama 1993, Maule and Mesa 1994, Mesa 1994). Most researchers have measured changes in plasma cortisol under laboratory conditions. Despite the abundance of research on stress in fish, only one study (Mesa 1994) has come close to simulating what fish may be experiencing on the Chena River. Mesa (1994) subjected fish to an agitation stress that consisted of pouring fish from a half full 19-L bucket into another bucket so that the fish fell about 1 m. The buckets were switched and the process was continued for 5 min. However, the agitation stress of Mesa (1994) is probably inadequate in imitating the pressure and turbulence that could be encountered during dam passage. Maule et al. (1988) investigated the physiological effects of collecting and transporting juvenile chinook salmon past dams on the Columbia River; their study may act as a useful guideline in predicting the potential levels of plasma cortisol that will be observed on the Chena River.

The accepted method for obtaining blood samples from small fish (≈100 mm in length) is to sever the caudal peduncle and remove blood from the caudal vasculature. This method is appropriate for chinook salmon on the Chena River, but insufficient quantities of blood are obtained from chum salmon using this blood sampling method. The dorsal gill incision technique developed by Watson et al. (1989) was designed for obtaining blood from fish <60 mm standard length. Although Watson et al. (1989) had success with this method in the lab, the method was troublesome with chum salmon under field conditions. Blood samples could have been pooled to obtain a complete sample but this would have required the sacrifice of unacceptable numbers of chum salmon. For these reasons, chum salmon stress response to capture and handling could not be investigated.

## Methods

Rotary screw traps were used to collect chinook salmon for blood sampling. Operation of the rotary screw traps was identical to that described in Chapter 1, except the trap was operated for a 2-h interval to insure that enough chinook salmon were captured to complete a 24-h sampling cycle. Chinook salmon pooled in the back of the live box were separated into 6 different containers: a 19 L (5 gal) bucket for fish to be sampled immediately and five separate 68 L (18 gal) perforated holding bins for fish to be sampled at 1, 3, 6, 12, and 24 hours after capture. The holding bins were secured in slack water near the trapping location and were designed to provide a fresh supply of oxygen and maintain natural Chena River water temperature. Care was exercised when transferring and retrieving fish from the holding tanks to minimize disturbance.

Fish were sacrificed in a lethal dose of MS-222 (200 mg/L). The caudal peduncle was severed with a razor blade and blood was collected with a cooled ammonium heparinized capillary tube. Blood collection for each fish was limited to 1.5 minutes to avoid blood coagulation. Capillary tubes were capped and refrigerated for future centrifugation. Five blood samples with a minimum of 20 μL of plasma each were needed for each sampling time. Blood was extracted from a minimum of eight chinook salmon during each sampling time because samples needed to be pooled to obtain enough blood for analysis. The actual number of chinook salmon sampled for each time period was determined at the time of blood extraction and depended on the amount of blood obtained from each fish during that time period.

After the 24-h sampling cycle was completed, refrigerated samples were transported to the lab and centrifuged in a MB Model micro-capillary centrifuge manufactured by the International Equipment Company, Boston, Massachusetts. The separated capillary tubes were frozen at -20 °C and stored for future assay. The capillary tubes were sent to Biotech Research and Consulting, Inc., Corvallis, Oregon, for plasma cortisol assay. The method used for analysis was an ELISA, which used a peroxidase-bound cortisol as a competitive reagent (D. Ewing, Biotech Research and Consulting, Inc., Corvallis, OR, personal communication).

At each location, the average cortisol concentrations for each sampling time were compared with a oneway ANOVA to identify if the means were significantly different at the $\alpha=0.05$ level (Glantz and Slinker 1990). For each site, the average cortisol concentrations at hours 1, 3, 6, 12, and 24 were individually compared to the average cortisol concentration at the time of capture using the Bonferroni multiple comparison procedure (Glantz and Slinker 1990). Because five comparisons were performed, the experiment-wide $\alpha$ level was 0.01 (Glantz and Slinker 1990). To identify if differences in the average cortisol concentrations existed among the sites, the average cortisol concentrations of the respective sampling hours were compared with the *F*-test (Neter et al. 1990).

The blood sampling protocol was performed twice: once at the upper trapping location and once at the lower trapping location. Any fish caught at the lower trapping location which was previously marked for other research purposes was not used for blood sampling. This insured that previously handled fish having potentially different physiological histories were not included in the blood sampling.

Blood sampling occurred during the 1996 field season. The cortisol concentrations at each trapping location were used to establish the elevation in cortisol that occurred due to capture and handling. Locational differences in plasma cortisol concentrations were investigated to identify if differences existed among the sites.

## Results

At both trapping locations, chinook salmon plasma cortisol levels were elevated for 3 h after capture and began to drop sometime after that (Figure 3.1 and 3.2). At the upper trapping location, maximum plasma cortisol level was 381.3 ng/mL and occurred during hour 0 (Figure 3.1). The cortisol concentration at hours 6, 12, and 24 were significantly lower than the cortisol concentration at the time of capture ($p<0.001$ in each comparison) (Figure 3.1).

The maximum plasma cortisol concentration at the lower trapping location occurred at hour 3 and was 349.3 ng/mL (Figure 3.2). The cortisol concentration at hour 24 was significantly lower than the cortisol concentration at the time of capture ($p=0.005$) (Figure 3.2).

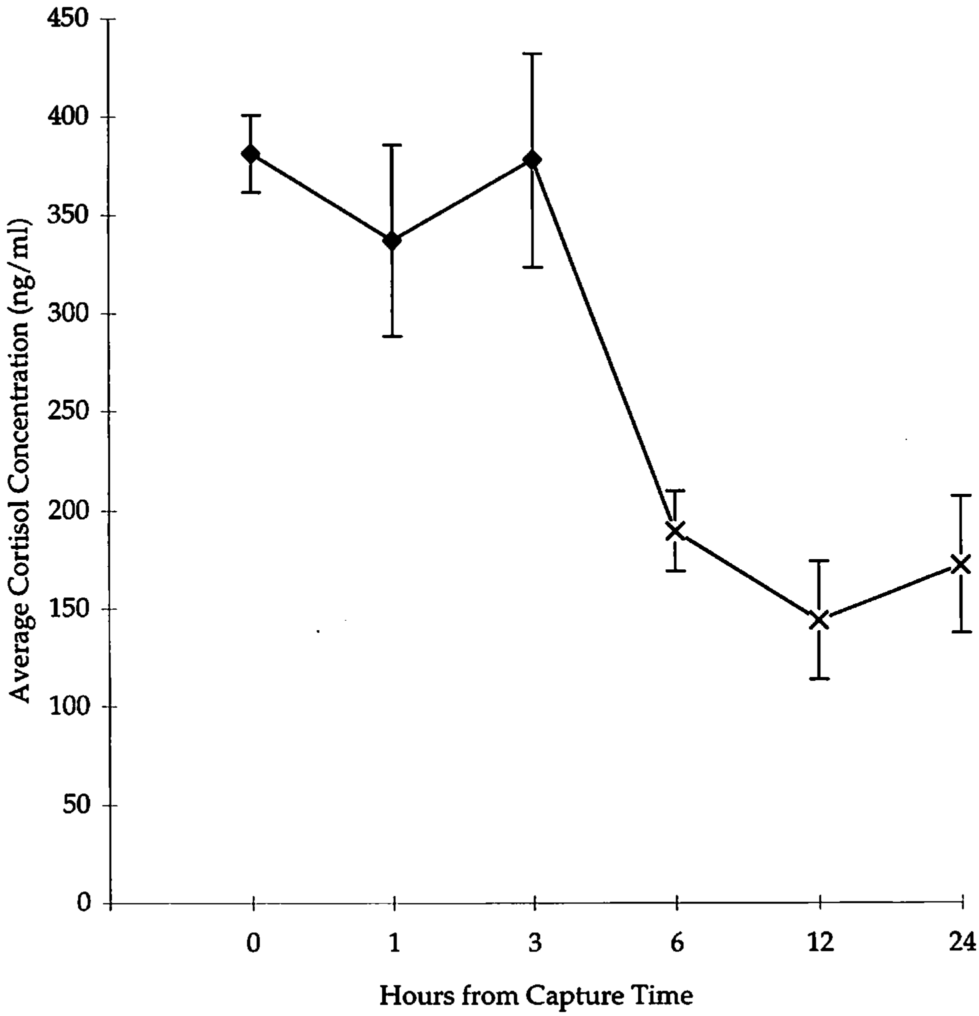



Figure 3.1. - Cortisol concentration of chinook salmon captured at the upper site,1996. Error bars represent the standard error. Data points marked (x) are significantly different from the cortisol concentration at the time of capture.

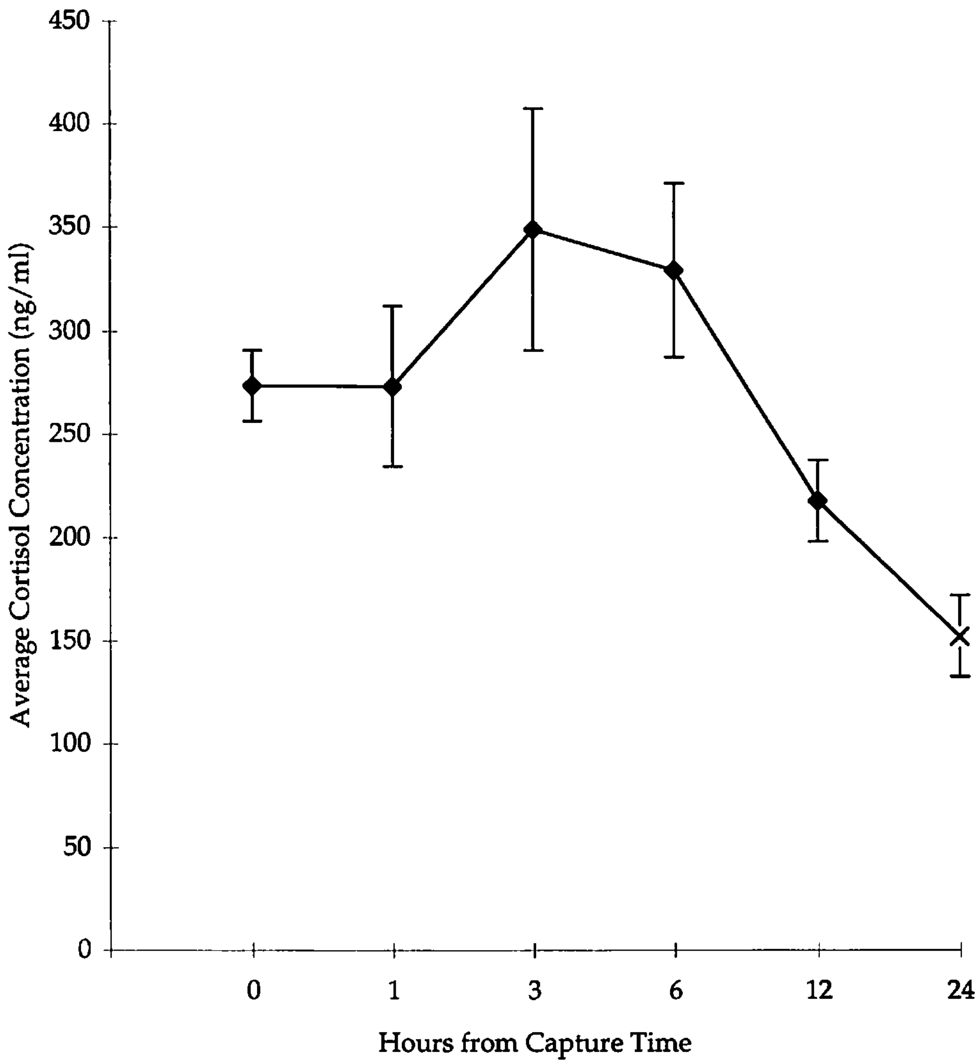



Figure 3.2. - Cortisol concentration of chinook salmon captured at the lower site,1996. Error bars represent the standard error. Data points marked (x) are significantly different from the cortisol concentration at the time of capture.

The average cortisol concentrations from the hour 0 ($p=0.005$) and hour 6 ($p=0.016$) sampling periods were significantly different among the sites (Figure 3.3).

## Discussion

The plasma cortisol concentration curves from my study are similar to curves of other salmonids exposed to acute stressors except for the elevated plasma cortisol levels at hour 0 (Schreck and Lorz 1978, Barton and Schreck 1987, Maule et al. 1988, Schreck et al. 1989, Avella et al. 1991, Pottinger et al. 1992, Salonius and Iwama 1993, Maule and Mesa 1994, Mesa 1994). A potential explanation for elevated cortisol levels at hour 0 could be the capture method. The rotary screw traps operated for 2 h before fish could be sampled. Therefore, it is unknown how long individual fish were in the live box of the trap before they were collected and separated into the respective holding bins. If capture by the screw trap is a source of stress for chinook salmon, then fish held in the live box for more than 1 h would possess elevated levels of plasma cortisol. These elevated levels would be evident in fish sampled in the hour 0 sampling time. Because plasma cortisol concentrations were elevated at hour 0 at both trapping locations, the rotary screw trap appears to be a source of stress for juvenile chinook salmon. The additional stressors of netting and transferring the fish to holding bins could cause the plasma cortisol levels to remain elevated (Figure 3.1) or increase the

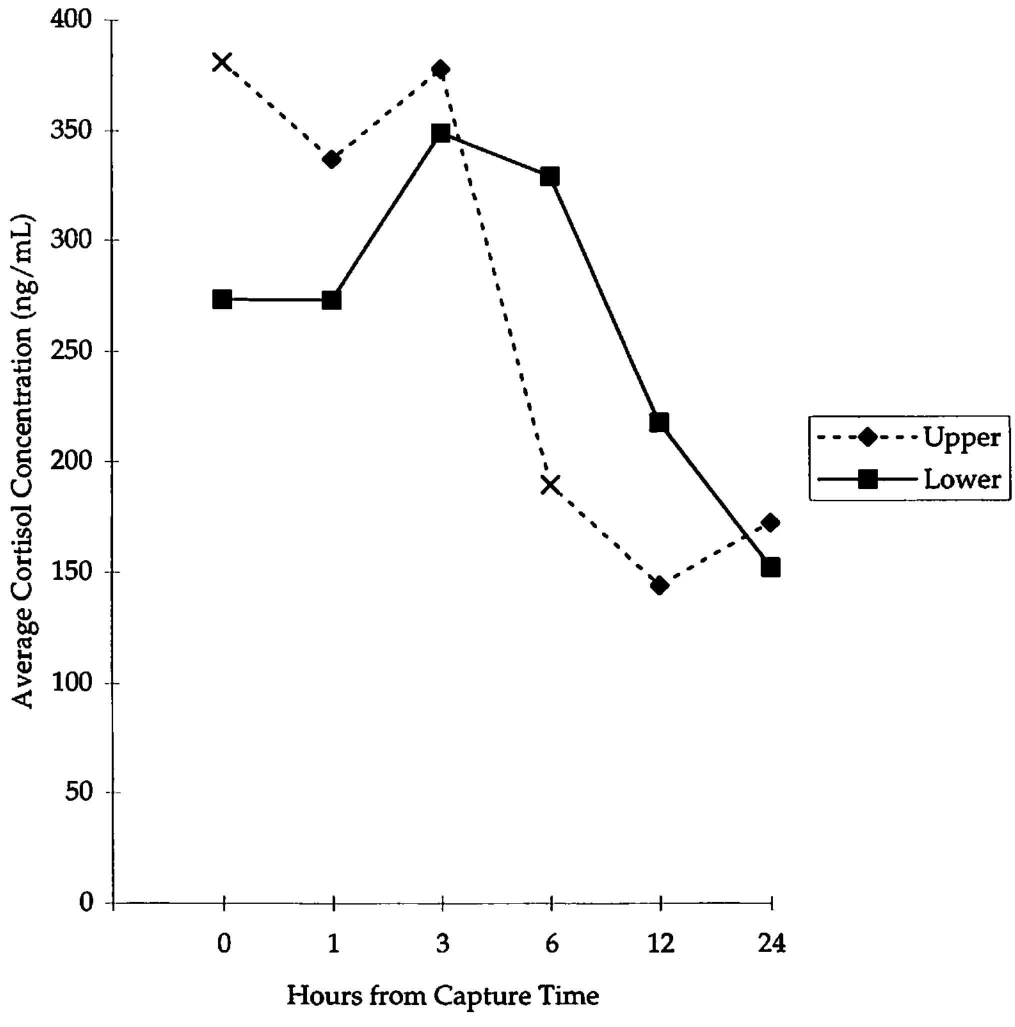



Figure 3.3. - Comparison of chinook salmon plasma cortisol concentrations at each site, 1996. Data points on the upper site line marked (x) are significantly different from the lower site cortisol concentration during the same sampling hour.

plasma cortisol concentration (Figure 3.2). This is consistent with other stress related research where multiple stressors sustain elevated plasma cortisol levels or elicit an additional elevation of plasma cortisol (Barton et al. 1986, Sigismondi and Weber 1988, Mesa 1994). Regardless of the source or severity of the stress, chinook salmon appear to be recovering after hour 3 (Figure 3.1 and 3.2).

There does not appear to be any substantial difference among the cortisol stress response curves at each site (Figure 3.3). Plasma cortisol was elevated for 3 hours after capture and then began to decline. The plasma cortisol concentrations from only two of the six sampling times were significantly different (Figure 3.3). Hence, location does not appear to affect the average plasma cortisol concentration.

Barton et al. (1986) demonstrated that juvenile chinook salmon showed a cumulative physiological stress response to multiple acute stressors. During a non-event year such as 1996, fish were subjected to two potential acute stressors: capture by the rotary screw trap and handling by field personnel. During an event year, dam passage may be an additional acute stressor for those fish captured below the dam which would cause additional plasma cortisol elevation in chinook salmon below the dam. Therefore, future blood chemistry investigations will be useful in establishing potential differences in the physiological status of juvenile chinook salmon above and below the dam during event years.

## Conclusions and Recommendations

The 1995 and 1996 field seasons provided an excellent opportunity to establish the natural condition of outmigrating juvenile chinook and chum salmon because no flood event was observed during the sampling period. The injury investigation revealed that, in all but one instance, the injury frequency was ≤7% regardless of the species or trapping location. Also, over half of the recorded injuries were classified as minor while few were considered severe. The frequency of chinook salmon scale loss ranged from 1-37%, with the majority of the scale loss identified as limited partial descaling.

The injury and scale loss investigation was easily integrated with trap operation. Neither trap (rotary screw trap and incline plane trap) required constant attention to operate. Hence, fish could be investigated for scale loss and injury while the traps were operating. Also, the lack of relation between water velocity and both injury and descaling frequency indicated that injury and scale loss was not velocity-related.

One disadvantage of the injury and scale loss investigations is the potential subjectivity of the method. For example, different observers may interpret an injury severity or a descaling percentage differently resulting in different information. However, after each field season, I investigated the field forms to identify if any patterns existed in a particular observer's interpretation and found no evidence of subjectivity. Also, the method allows room for interpretation. For example, partial descaling described any chinook salmon with scale loss between 3-20% of the body surface area while descaling described scale loss >20% of the body surface area. Hence, two observers may have estimated the same scale loss differently, but as long as they are within the same classification range, similar conclusions would result. In addition, large sample sizes (i.e. $\geq$ 100 fish) tend to minimize observer bias (P. Wagner, Bonneville Power Administration, McNary Dam, Columbia River, personal communication).

Another potential drawback of the injury and descaling investigation is that fish could be stressed or adversely affected without exhibiting physical signs of these effects. Therefore, by observing physical injury alone, it is possible that adverse effects could go unnoticed.

Despite the potential disadvantages of using the injury and scale loss procedure, I would choose this investigation over the predator avoidance and plasma cortisol investigations. The method proved to be simple and easily taught to field personnel. The procedure provided abundant information with a reasonable amount of effort and did not require specialized equipment. Also, if operation of the Chena River Dam during a flood event does cause physical injury to emigrating juvenile salmonids, this investigation would likely identify the difference in fish condition.

Analysis of Arctic grayling stomach contents indicated that juvenile salmonids were a diminutive portion of the Arctic grayling diet. Intuitively, I would expect predation by Arctic grayling on juvenile chum salmon to be much greater than observed during the length of the project. Arctic grayling are opportunistic feeders and chum salmon are a plentiful food source for a short period of time. However, my results are not different from what is known about Arctic grayling diet in Alaska (Armstrong 1986).

The Arctic grayling stomach content analysis allowed me to make inferences regarding the differences in the predator avoidance ability of chum salmon upstream and downstream of the Chena River Dam. Predator avoidance is an excellent measure of stress in fish because it involves a number of complex processes and requires the fish to be in good physiological condition in order to perform the task of predator avoidance. However, the procedure was not sufficient to determine what, if anything, was unique about ingested chum salmon. There is no information about the condition of chum salmon upon ingestion. Petersen (1994) cautions that mortality estimates due to consumption may be high because fish could be dead prior to ingestion.

The blood chemistry analysis of chinook salmon demonstrated that Chena River chinook respond predictably to the acute stress of capture and handling. Blood chemistry analysis of plasma cortisol levels provides very specialized information about the primary stress response of fish. Blood samples were easily obtainable, however, plasma cortisol analysis was not readily available because samples needed to be sent to Oregon. Therefore, plasma cortisol data were not available in the field and could not be used to make real-time decisions about the relation of fish health and dam operation. Cortisol concentrations cannot be used to determine the extent of the stress level. For example, cortisol concentration will not indicate if various internal or external systems are affected by the stress.

Each method indicates that outmigrating Chena River chinook and chum salmon were in good condition under the natural environment encountered during the project. The goal of the present study was to evaluate the possible effects of Chena River Dam operation on the condition of outmigrating salmonids. With the present data, this goal cannot be met. However, the data will serve as a basis of comparison for future studies on the Chena River during flood events.

# Appendix A

## Daily Injury Frequency Tables by Species, Site, and Year

Table A.1. - Chum salmon injury frequency at the upper site, 1995.

| Date | Water Velocity (cm/s) | Captured | Injured | % Injured |
|---|---|---|---|---|
| 5/22/95 | 68 | 34 | 4 | 12 |
| 5/23/95 | 65 | 8 | 3 | 38 |
| 5/24/95 | 70 | 16 | 2 | 13 |
| 5/25/95 | 65 | 17 | 2 | 12 |
| 5/26/95 | 60 | 17 | 3 | 18 |
| 5/27/95 | 63 | 57 | 9 | 16 |
| 5/28/95 | 69 | 56 | 2 | 4 |
| 5/29/95 | 68 | 151 | 2 | 1 |
| 5/30/95 | 55 | 84 | 0 | 0 |
| 5/31/95 | 60 | 121 | 4 | 3 |
| 6/1/95 | 64 | 27 | 0 | 0 |
| 6/2/95 | 56 | 124 | 2 | 2 |
| 6/3/95 | 61 | 86 | 3 | 3 |
| 6/4/95 | 67 | 130 | 1 | 1 |
| 6/5/95 | 67 | 166 | 0 | 0 |
| 6/6/95 | 72 | 108 | 2 | 2 |
| 6/7/95 | 62 | 83 | 1 | 1 |
| 6/8/95 | 64 | 64 | 0 | 0 |
| 6/10/95 | 62 | 277 | 5 | 2 |
| 6/11/95 | 54 | 232 | 6 | 3 |
| 6/12/95 | 55 | 232 | 13 | 6 |
| 6/13/95 | 54 | 270 | 14 | 5 |
| 6/14/95 | 50 | 101 | 7 | 7 |
| 6/15/95 | 51 | 162 | 3 | 2 |
| 6/16/95 | 47 | 106 | 2 | 2 |
| 6/18/95 | 92 | 99 | 10 | 10 |
| 6/19/95 | 97 | 39 | 2 | 5 |
| 6/20/95 | 100 | 0 | 0 | 0 |
| 6/21/95 | 96 | 1 | 0 | 0 |
| 6/22/95 | 97 | 4 | 0 | 0 |
| Totals | | 2872 | 102 | 4 |

Table A.2. - Chinook salmon injury frequency at the upper site, 1995.

| Date | Water Velocity (cm/s) | Captured | Injured | % Injured |
|---|---|---|---|---|
| 5/22/95 | 68 | 2 | 1 | 50 |
| 5/23/95 | 65 | 4 | 2 | 50 |
| 5/24/95 | 70 | 2 | 1 | 50 |
| 5/25/95 | 65 | 2 | 1 | 50 |
| 5/26/95 | 60 | 0 | 0 | 0 |
| 5/27/95 | 63 | 1 | 1 | 100 |
| Totals | | 11 | 6 | 55 |

Table A.3. - Chum salmon injury frequency at the lower site, 1995.

| Date | Water Velocity (cm/s) | Captured | Injured | % Injured |
|---|---|---|---|---|
| 5/23/95 | 110 | 43 | 5 | 12 |
| 5/24/95 | 94 | 14 | 1 | 7 |
| 5/25/95 | 107 | 9 | 1 | 11 |
| 5/26/95 | 110 | 25 | 1 | 4 |
| 5/27/95 | 120 | 176 | 10 | 6 |
| 5/28/95 | 113 | 53 | 4 | 8 |
| 5/29/95 | 110 | 4 | 0 | 0 |
| 5/30/95 | 104 | 42 | 2 | 5 |
| 5/31/95 | 117 | 79 | 5 | 6 |
| 6/1/95 | 107 | 38 | 3 | 8 |
| 6/2/95 | 107 | 6 | 1 | 17 |
| 6/3/95 | 101 | 99 | 3 | 3 |
| 6/4/95 | 123 | 432 | 33 | 8 |
| 6/5/95 | 120 | 136 | 15 | 11 |
| 6/6/95 | 110 | 12 | 1 | 8 |
| 6/7/95 | 101 | 11 | 0 | 0 |
| 6/10/95 | 94 | 7 | 2 | 29 |
| 6/11/95 | 88 | 5 | 0 | 0 |
| 6/16/95 | 88 | 1 | 0 | 0 |
| 6/17/95 | 88 | 6 | 0 | 0 |
| 6/18/95 | 88 | 1 | 0 | 0 |
| 6/19/95 | 81 | 2 | 0 | 0 |
| 6/22/95 | 81 | 1 | 1 | 100 |
| 6/28/95 | 129 | 0 | 0 | 0 |
| Totals | | 1202 | 88 | 7 |

Table A.4. - Chinook salmon injury frequency at the lower site, 1995.

| Date | Water Velocity (cm/s) | Captured | Injured | % Injured |
|---|---|---|---|---|
| 5/23/95 | 110 | 33 | 0 | 0 |
| 5/24/95 | 94 | 13 | 0 | 0 |
| 5/25/95 | 107 | 13 | 0 | 0 |
| 5/26/95 | 110 | 7 | 0 | 0 |
| 5/27/95 | 120 | 17 | 1 | 6 |
| 5/28/95 | 113 | 3 | 0 | 0 |
| 5/29/95 | 110 | 1 | 0 | 0 |
| 5/30/95 | 104 | 1 | 0 | 0 |
| 5/31/95 | 117 | 0 | 0 | 0 |
| 6/1/95 | 107 | 1 | 0 | 0 |
| 6/2/95 | 107 | 0 | 0 | 0 |
| 6/3/95 | 101 | 1 | 1 | 100 |
| 6/4/95 | 123 | 28 | 0 | 0 |
| 6/5/95 | 120 | 2 | 0 | 0 |
| 6/6/95 | 110 | 1 | 0 | 0 |
| 6/7/95 | 101 | 0 | 0 | 0 |
| 6/10/95 | 94 | 0 | 0 | 0 |
| 6/11/95 | 88 | 0 | 0 | 0 |
| 6/16/95 | 88 | 0 | 0 | 0 |
| 6/17/95 | 88 | 0 | 0 | 0 |
| 6/18/95 | 88 | 0 | 0 | 0 |
| 6/19/95 | 81 | 0 | 0 | 0 |
| 6/22/95 | 81 | 0 | 0 | 0 |
| 6/28/95 | 129 | 14 | 1 | 7 |
| Totals | | 135 | 3 | 2 |

Table A.5. - Chum salmon injury frequency at the upper site, 1996.

| Date | Water Velocity (cm/s) | Captured | Injured | % Injured |
|---|---|---|---|---|
| 5/6/96 | 6.75 | 16 | 2 | 13 |
| 5/7/96 | 4.75 | 166 | 7 | 4 |
| 5/8/96 | 5 | 99 | 0 | 0 |
| 5/10/96 | 5.25 | 72 | 6 | 8 |
| 5/11/96 | 6.75 | 110 | 3 | 3 |
| 5/12/96 | 7.5 | 100 | 2 | 2 |
| 5/13/96 | 5.5 | 107 | 3 | 3 |
| 5/14/96 | 6.5 | 67 | 0 | 0 |
| 5/15/96 | 8.25 | 29 | 0 | 0 |
| 5/16/96 | 8 | 30 | 2 | 7 |
| 5/17/96 | 8 | 59 | 0 | 0 |
| 5/18/96 | 8 | 9 | 0 | 0 |
| 5/19/96 | 7.5 | 11 | 0 | 0 |
| 5/20/96 | 7 | 12 | 0 | 0 |
| 5/21/96 | 6.75 | 22 | 0 | 0 |
| 5/22/96 | 6.75 | 11 | 0 | 0 |
| 5/23/96 | 7 | 14 | 0 | 0 |
| 5/24/96 | 8 | 22 | 2 | 9 |
| 5/25/96 | 7.5 | 16 | 0 | 0 |
| 5/26/96 | 7.5 | 6 | 0 | 0 |
| 5/27/96 | 7 | 15 | 0 | 0 |
| 5/28/96 | 7.25 | 15 | 0 | 0 |
| 5/29/96 | 7.25 | 11 | 0 | 0 |
| 5/30/96 | 7.25 | 20 | 0 | 0 |
| 5/31/96 | 6.5 | 25 | 0 | 0 |
| 6/1/96 | 6.5 | 15 | 1 | 7 |
| 6/2/96 | 6.25 | 10 | 0 | 0 |
| 6/3/96 | 6.25 | 5 | 0 | 0 |
| 6/4/96 | 5.75 | 8 | 0 | 0 |
| 6/5/96 | 5.5 | 5 | 0 | 0 |
| 6/6/96 | 4.5 | 2 | 0 | 0 |
| 6/7/96 | 4.5 | 2 | 0 | 0 |
| 6/8/96 | 4.25 | 2 | 0 | 0 |
| 6/10/96 | 4.5 | 3 | 0 | 0 |
| Totals |  | 1,116 | 28 | 3 |

Table A.6. - Chinook salmon injury frequency at the upper site, 1996.

| Date | Water Velocity (cm/s) | Captured | Injuries | % Injured |
|---|---|---|---|---|
| 5/6/96 | 6.75 | 4 | 0 | 0 |
| 5/7/96 | 4.75 | 204 | 11 | 5 |
| 5/8/96 | 5.00 | 96 | 4 | 4 |
| 5/10/96 | 5.25 | 102 | 9 | 9 |
| 5/11/96 | 6.75 | 100 | 6 | 6 |
| 5/12/96 | 7.50 | 100 | 8 | 8 |
| 5/13/96 | 5.50 | 100 | 6 | 6 |
| 5/14/96 | 6.50 | 29 | 8 | 28 |
| 5/15/96 | 8.25 | 68 | 4 | 6 |
| 5/16/96 | 8.00 | 100 | 4 | 4 |
| 5/17/96 | 8.00 | 114 | 8 | 7 |
| 5/18/96 | 8.00 | 47 | 6 | 13 |
| 5/19/96 | 7.50 | 50 | 1 | 2 |
| 5/20/96 | 7.00 | 50 | 4 | 8 |
| 5/21/96 | 7.00 | 53 | 1 | 2 |
| 5/22/96 | 6.75 | 88 | 2 | 2 |
| 5/23/96 | 7.00 | 47 | 1 | 2 |
| 5/24/96 | 8.25 | 56 | 3 | 5 |
| 5/25/96 | 7.50 | 57 | 6 | 11 |
| 5/26/96 | 7.50 | 32 | 1 | 3 |
| 5/27/96 | 7.00 | 85 | 2 | 2 |
| 5/28/96 | 7.25 | 52 | 3 | 6 |
| 5/29/96 | 7.25 | 20 | 2 | 10 |
| 5/30/96 | 7.25 | 15 | 1 | 7 |
| 5/31/96 | 6.50 | 10 | 1 | 10 |
| 6/1/96 | 6.50 | 25 | 4 | 16 |
| 6/2/96 | 6.25 | 12 | 3 | 25 |
| 6/3/96 | 6.25 | 18 | 1 | 6 |
| 6/4/96 | 5.75 | 23 | 0 | 0 |
| 6/5/96 | 5.50 | 3 | 0 | 0 |
| 6/6/96 | 4.50 | 3 | 0 | 0 |
| 6/7/96 | 4.50 | 3 | 0 | 0 |
| 6/8/96 | 4.25 | 2 | 1 | 50 |
| 6/9/96 | 4.00 | 1 | 0 | 0 |
| 6/10/96 | 4.50 | 3 | 0 | 0 |
| Totals | | 1,772 | 111 | 6 |

Table A.7. - Chum salmon injury frequency at the middle site, 1996.

| Date | Captured (N) | Injured (N) | % Injured |
|---|---|---|---|
| 5/8/96 | 4 | 0 | 0 |
| 5/9/96 | 30 | 1 | 3 |
| 5/10/96 | 17 | 0 | 0 |
| 5/11/96 | 17 | 1 | 6 |
| 5/12/96 | 26 | 0 | 0 |
| 5/13/96 | 28 | 0 | 0 |
| 5/14/96 | 7 | 0 | 0 |
| 5/15/96 | 9 | 0 | 0 |
| 5/16/96 | 11 | 1 | 9 |
| 5/17/96 | 34 | 1 | 3 |
| 5/18/96 | 8 | 0 | 0 |
| 5/19/96 | 12 | 0 | 0 |
| 5/20/96 | 6 | 0 | 0 |
| 5/21/96 | 3 | 0 | 0 |
| 5/23/96 | 12 | 0 | 0 |
| 5/24/96 | 7 | 0 | 0 |
| 5/25/96 | 10 | 0 | 0 |
| 5/26/96 | 1 | 0 | 0 |
| 5/27/96 | 5 | 0 | 0 |
| 5/28/96 | 2 | 0 | 0 |
| 5/29/96 | 14 | 0 | 0 |
| 5/30/96 | 31 | 1 | 3 |
| 5/31/96 | 4 | 0 | 0 |
| 6/1/96 | 3 | 0 | 0 |
| 6/2/96 | 1 | 0 | 0 |
| 6/3/96 | 1 | 0 | 0 |
| 6/4/96 | 3 | 0 | 0 |
| 6/5/96 | 3 | 0 | 0 |
| 6/6/96 | 1 | 0 | 0 |
| 6/7/96 | 1 | 0 | 0 |
| 6/9/96 | 1 | 0 | 0 |
| 6/10/96 | 3 | 0 | 0 |
| Totals | 315 | 5 | 2 |

Table A.8. - Chinook salmon injury frequency at the middle site, 1996.

| Date | Captured (N) | Injured (N) | % Injured |
|---|---|---|---|
| 5/8/96 | 67 | 4 | 6 |
| 5/9/96 | 131 | 7 | 5 |
| 5/10/96 | 104 | 0 | 0 |
| 5/11/96 | 110 | 4 | 4 |
| 5/12/96 | 113 | 2 | 2 |
| 5/13/96 | 87 | 3 | 3 |
| 5/14/96 | 20 | 0 | 0 |
| 5/15/96 | 79 | 0 | 0 |
| 5/16/96 | 68 | 0 | 0 |
| 5/17/96 | 72 | 2 | 3 |
| 5/18/96 | 33 | 0 | 0 |
| 5/19/96 | 41 | 4 | 10 |
| 5/20/96 | 52 | 3 | 6 |
| 5/21/96 | 57 | 3 | 5 |
| 5/22/96 | 31 | 0 | 0 |
| 5/23/96 | 97 | 4 | 4 |
| 5/24/96 | 76 | 7 | 9 |
| 5/25/96 | 84 | 4 | 5 |
| 5/26/96 | 24 | 2 | 8 |
| 5/27/96 | 22 | 1 | 5 |
| 5/28/96 | 15 | 0 | 0 |
| 5/29/96 | 15 | 1 | 7 |
| 5/30/96 | 11 | 3 | 27 |
| 5/31/96 | 4 | 0 | 0 |
| 6/1/96 | 12 | 1 | 8 |
| 6/2/96 | 10 | 2 | 20 |
| 6/3/96 | 8 | 1 | 13 |
| 6/4/96 | 2 | 0 | 0 |
| 6/5/96 | 9 | 0 | 0 |
| 6/6/96 | 4 | 0 | 0 |
| 6/7/96 | 3 | 0 | 0 |
| 6/8/96 | 1 | 0 | 0 |
| 6/9/96 | 3 | 0 | 0 |
| 6/10/96 | 3 | 0 | 0 |
| Totals | 1,468 | 58 | 4 |

Table A.9. - Chum salmon injury frequency at the lower site, 1996.

| Date | Water Velocity (cm/s) | Captured | Injured | % Injured |
|---|---|---|---|---|
| 5/6/96 | 6 | 214 | 6 | 3 |
| 5/7/96 | 7 | 149 | 4 | 3 |
| 5/8/96 | 7.75 | 243 | 8 | 3 |
| 5/9/96 | 7.5 | 207 | 16 | 8 |
| 5/10/96 | 7.25 | 138 | 9 | 7 |
| 5/11/96 | 7.5 | 166 | 9 | 5 |
| 5/12/96 | 7.5 | 286 | 13 | 5 |
| 5/13/96 | 7.5 | 105 | 7 | 7 |
| 5/14/96 | 7.5 | 108 | 6 | 6 |
| 5/15/96 | 7 | 91 | 4 | 4 |
| 5/16/96 | 7.25 | 89 | 3 | 3 |
| 5/17/96 | 7 | 100 | 6 | 6 |
| 5/18/96 | 7 | 88 | 6 | 7 |
| 5/19/96 | 6.5 | 72 | 1 | 1 |
| 5/20/96 | 6.5 | 18 | 1 | 6 |
| 5/21/96 | 6.5 | 45 | 2 | 4 |
| 5/22/96 | 6.5 | 18 | 0 | 0 |
| 5/23/96 | 7 | 85 | 1 | 1 |
| 5/24/96 | 7.75 | 89 | 4 | 4 |
| 5/25/96 | 7.25 | 100 | 8 | 8 |
| 5/26/96 | 7.75 | 40 | 1 | 3 |
| 5/27/96 | 7.5 | 19 | 0 | 0 |
| 5/28/96 | 7.5 | 42 | 3 | 7 |
| 5/29/96 | 7.5 | 46 | 0 | 0 |
| 5/30/96 | 6.5 | 14 | 2 | 14 |
| 5/31/96 | 6.5 | 31 | 2 | 6 |
| 6/1/96 | 7 | 60 | 7 | 12 |
| 6/2/96 | 6 | 10 | 0 | 0 |
| 6/3/96 | 6.5 | 6 | 0 | 0 |
| 6/4/96 | 6.5 | 22 | 0 | 0 |
| 6/5/96 | 7 | 13 | 0 | 0 |
| 6/6/96 | 4.5 | 4 | 0 | 0 |
| 6/7/96 | 4.5 | 1 | 0 | 0 |
| 6/8/96 | 4 | 3 | 0 | 0 |
| 6/9/96 | 4.5 | 16 | 0 | 0 |
| 6/10/96 | 4.5 | 1 | 0 | 0 |
| Totals | | 2,739 | 129 | 5 |

Table A.10. - Chinook salmon injury frequency at the lower site, 1996.

| Date | Water Velocity (cm/s) | Captured | Injured | % Injured |
|---|---|---|---|---|
| 5/6/96 | 6 | 140 | 5 | 4 |
| 5/7/96 | 7 | 294 | 4 | 1 |
| 5/8/96 | 7.75 | 247 | 4 | 2 |
| 5/9/96 | 7.5 | 234 | 15 | 6 |
| 5/10/96 | 7.25 | 345 | 13 | 4 |
| 5/11/96 | 7.5 | 600 | 21 | 4 |
| 5/12/96 | 7.5 | 546 | 25 | 5 |
| 5/13/96 | 7.5 | 103 | 4 | 4 |
| 5/14/96 | 7.5 | 78 | 9 | 12 |
| 5/15/96 | 7 | 93 | 6 | 6 |
| 5/16/96 | 7.25 | 100 | 2 | 2 |
| 5/17/96 | 7 | 102 | 4 | 4 |
| 5/18/96 | 7 | 101 | 6 | 6 |
| 5/19/96 | 6.5 | 54 | 2 | 4 |
| 5/20/96 | 6.5 | 107 | 4 | 4 |
| 5/21/96 | 6.5 | 105 | 8 | 8 |
| 5/22/96 | 6.5 | 102 | 6 | 6 |
| 5/23/96 | 7 | 103 | 14 | 14 |
| 5/24/96 | 7.75 | 101 | 7 | 7 |
| 5/25/96 | 7.25 | 104 | 4 | 4 |
| 5/26/96 | 7.75 | 100 | 11 | 11 |
| 5/27/96 | 7.5 | 103 | 0 | 0 |
| 5/28/96 | 7.5 | 102 | 11 | 11 |
| 5/29/96 | 7.5 | 29 | 0 | 0 |
| 5/30/96 | 6.5 | 11 | 3 | 27 |
| 5/31/96 | 6.5 | 14 | 0 | 0 |
| 6/1/96 | 6.5 | 29 | 4 | 14 |
| 6/2/96 | 6 | 17 | 3 | 18 |
| 6/3/96 | 6.5 | 5 | 0 | 0 |
| 6/4/96 | 6.5 | 4 | 0 | 0 |
| 6/5/96 | 7 | 1 | 0 | 0 |
| 6/6/96 | 4.5 | 1 | 0 | 0 |
| 6/7/96 | 4.5 | 1 | 0 | 0 |
| 6/8/96 | 4 | 2 | 1 | 50 |
| 6/9/96 | 4.5 | 1 | 0 | 0 |
| 6/10/96 | 4.5 | 2 | 0 | 0 |
| Totals | | 4,081 | 196 | 5 |

# Appendix B

## Relation of Injury or Descaling Frequencies to Water Velocity

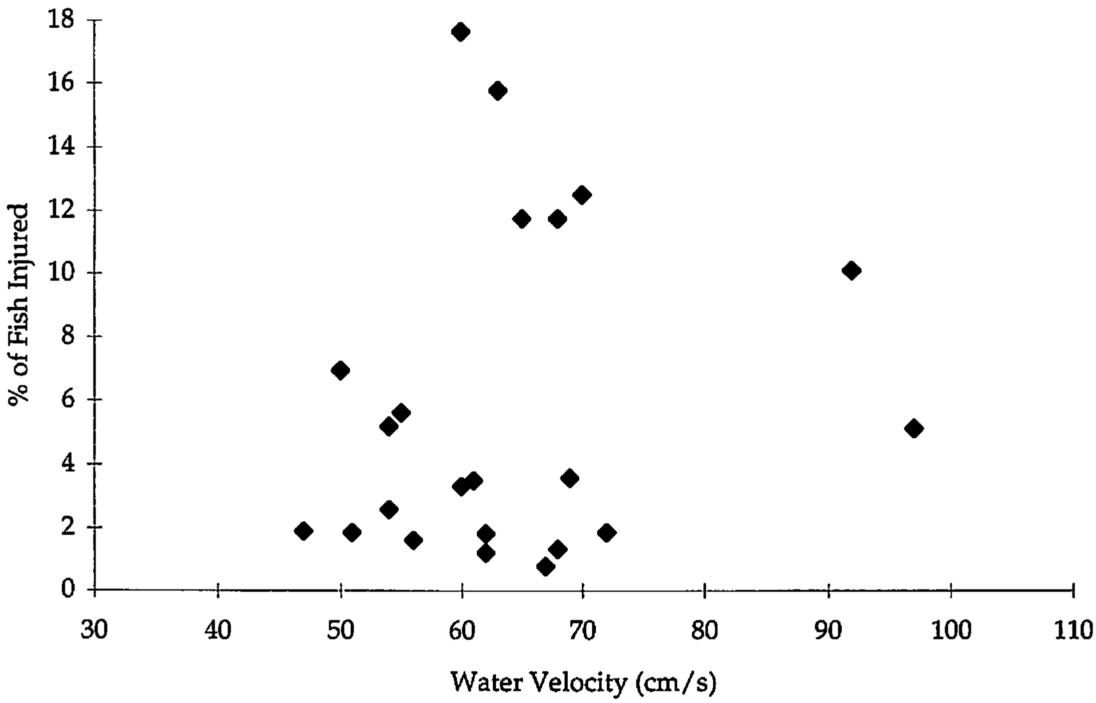



Figure B.1. - Scatter plot of chum salmon injury frequency versus water velocity at the upper site, 1995.

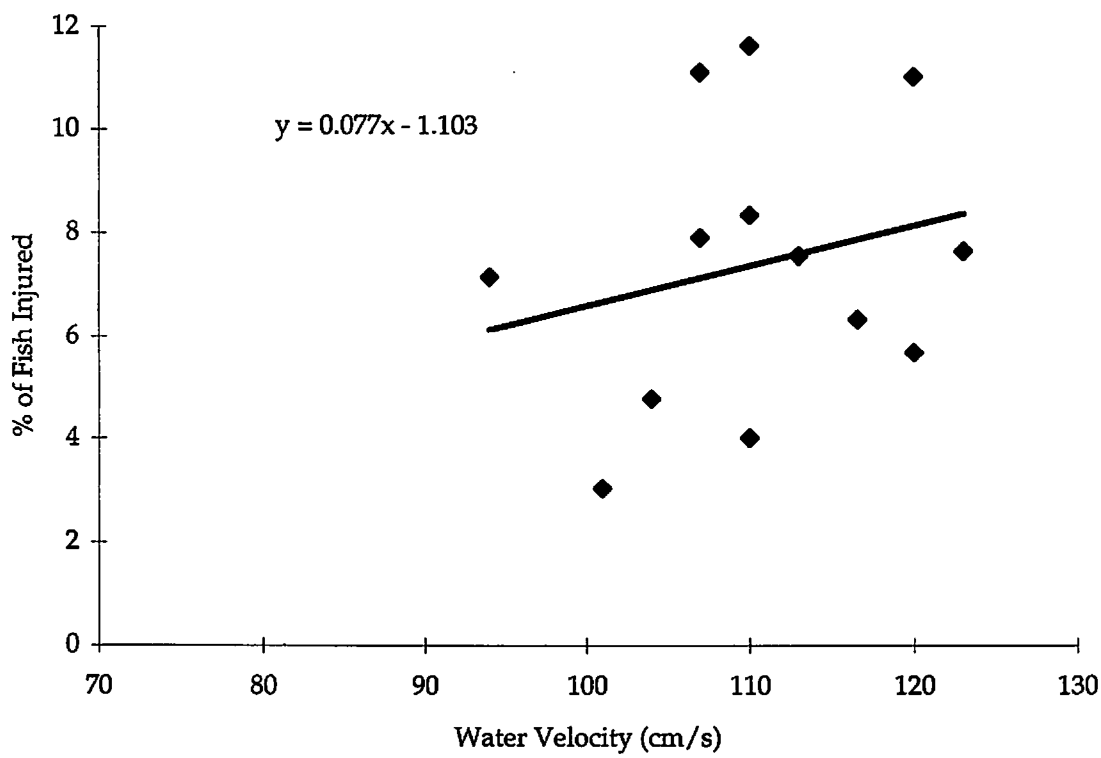



Figure B.2. - Relation of chum salmon injury frequency and water velocity at the lower site, 1995.

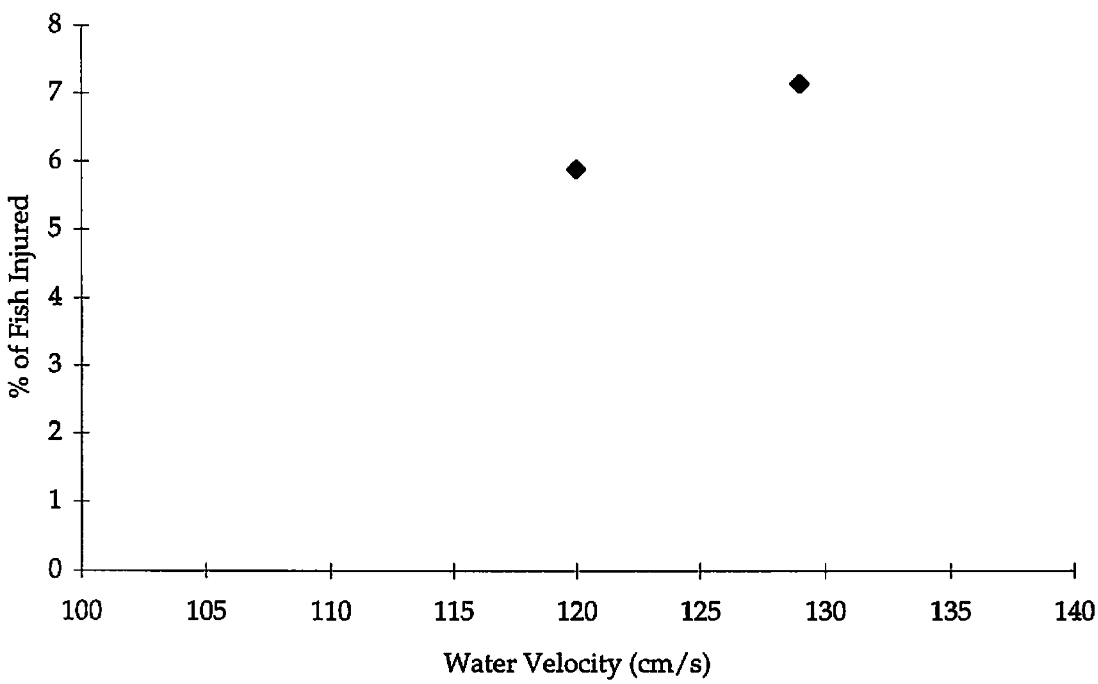



Figure B.3. - Scatter plot of chinook salmon injury frequency versus water velocity at the lower site, 1995.

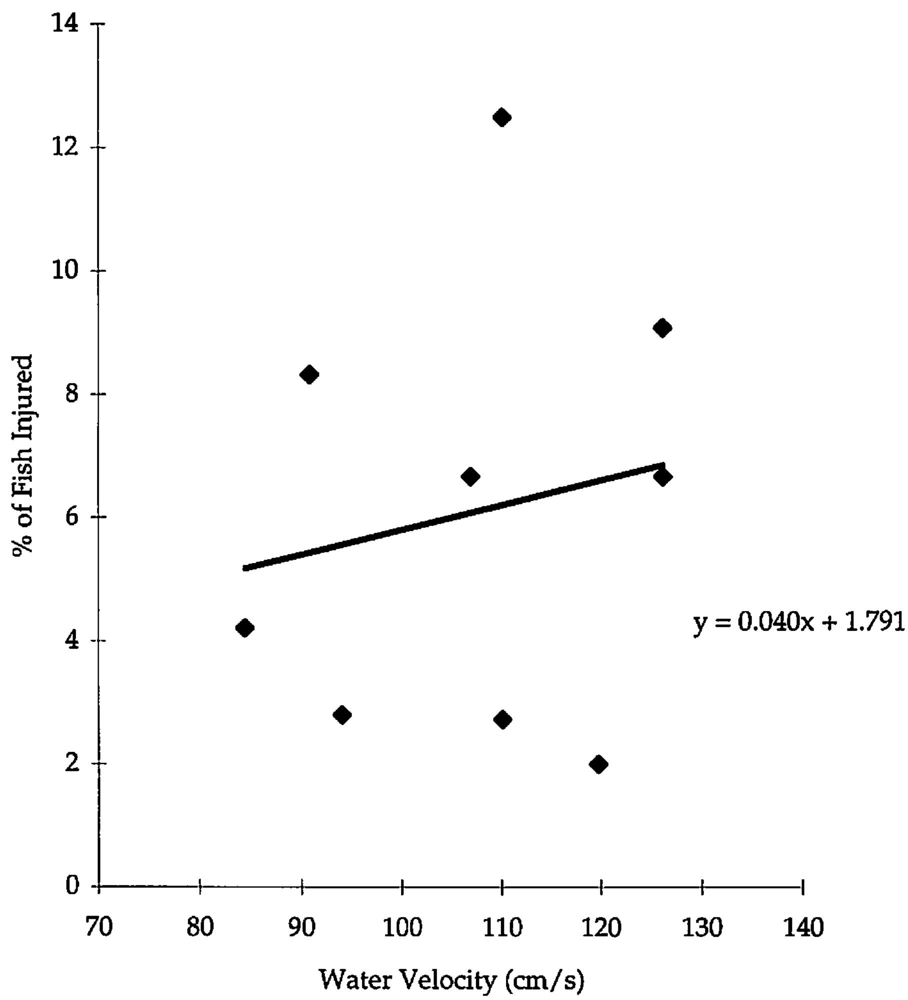



Figure B.4. - Relation of chum salmon injury frequency to water velocity at the upper site, 1996.

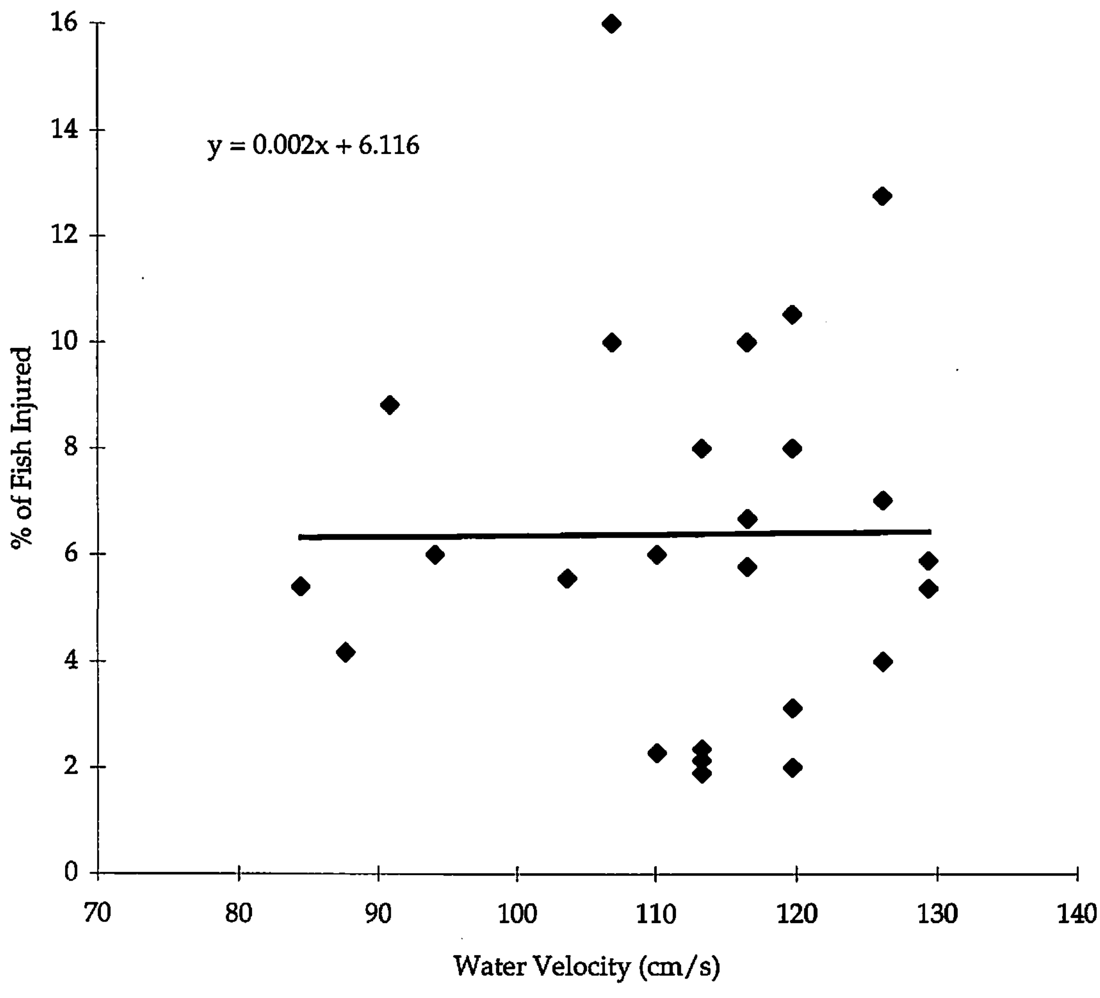



Figure B.5. - Relation of chinook salmon injury frequency to water velocity at the upper site, 1996.

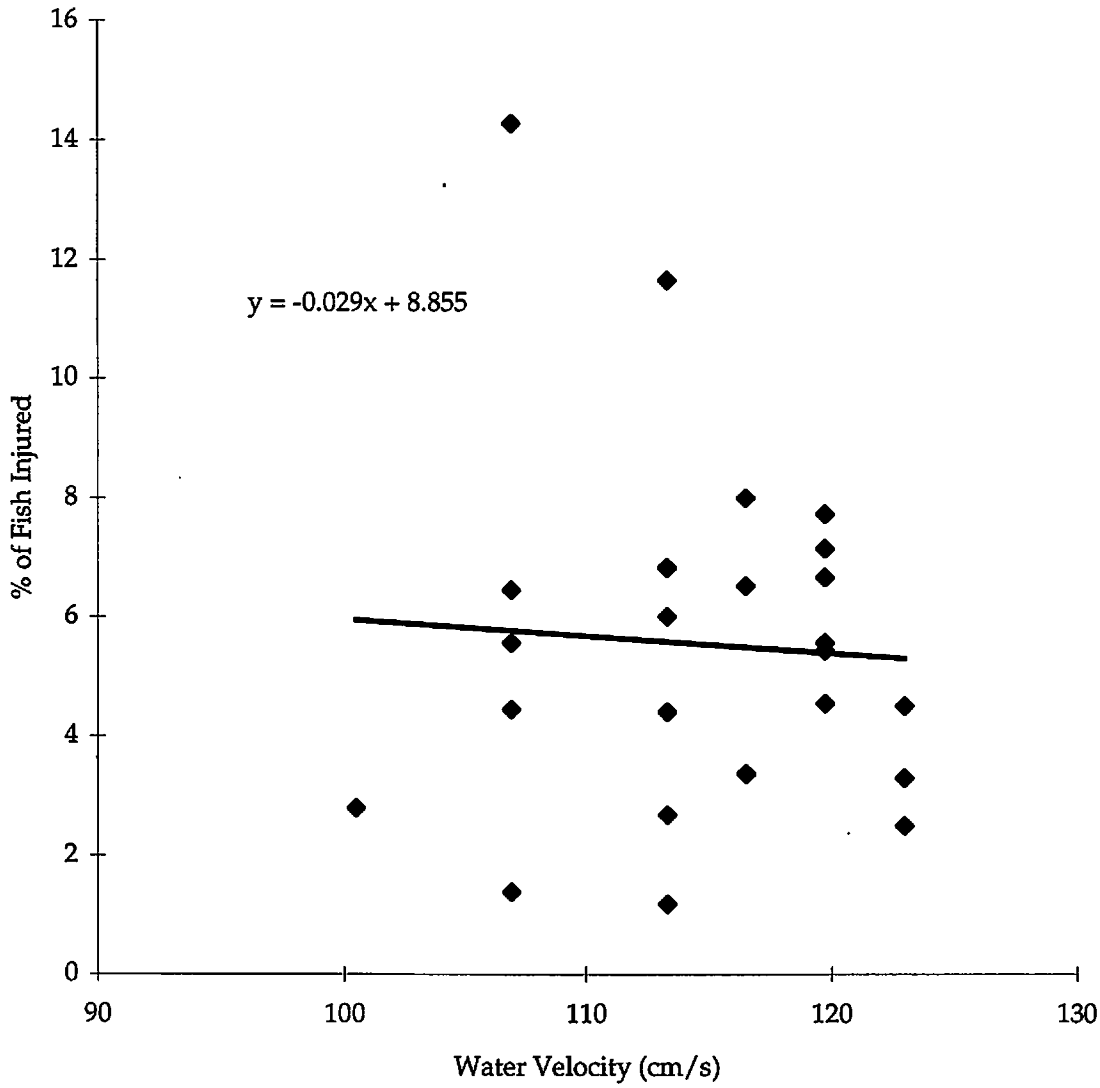



Figure B.6. - Relation of chum salmon injury frequency to water velocity at the lower site, 1996.

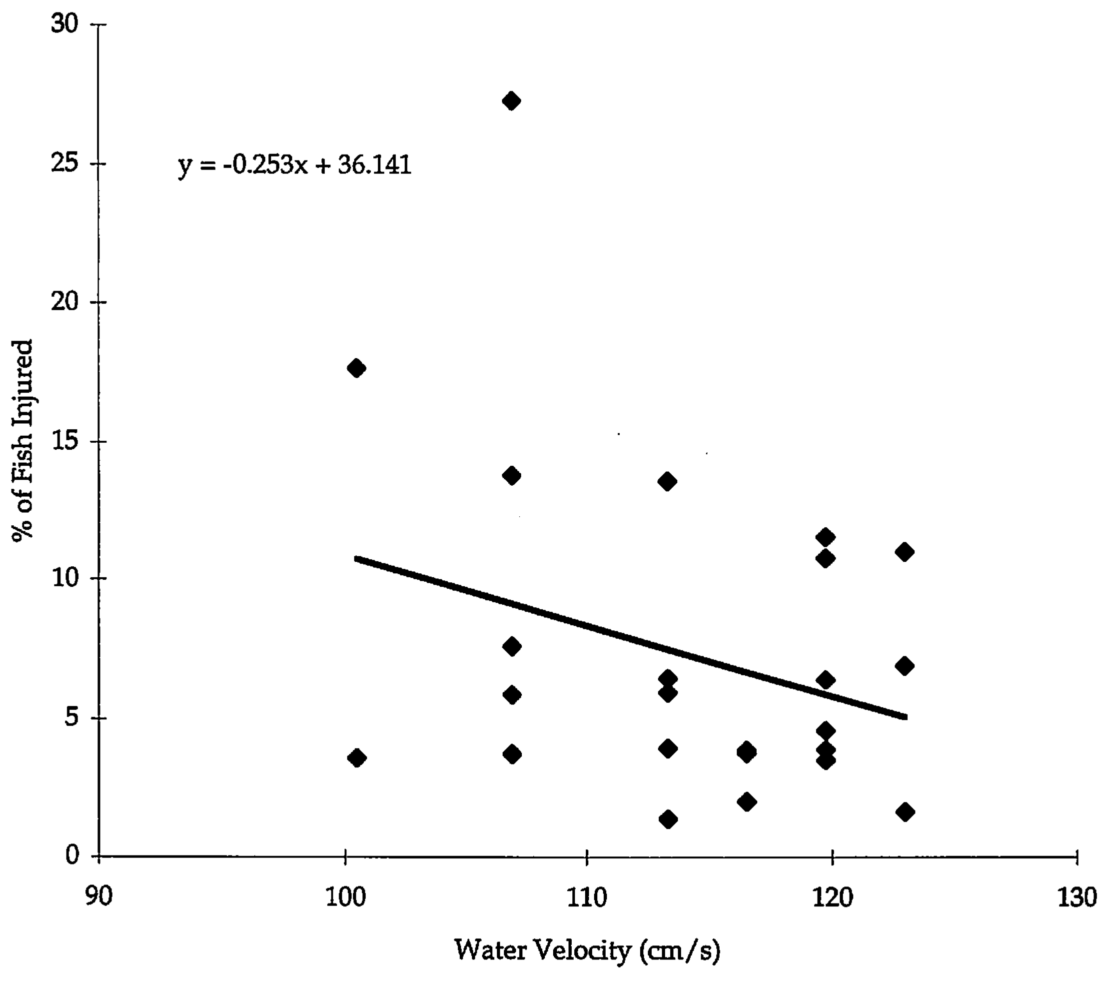



Figure B.7. - Relation of chinook salmon injury frequency to water velocity at the lower site, 1996.

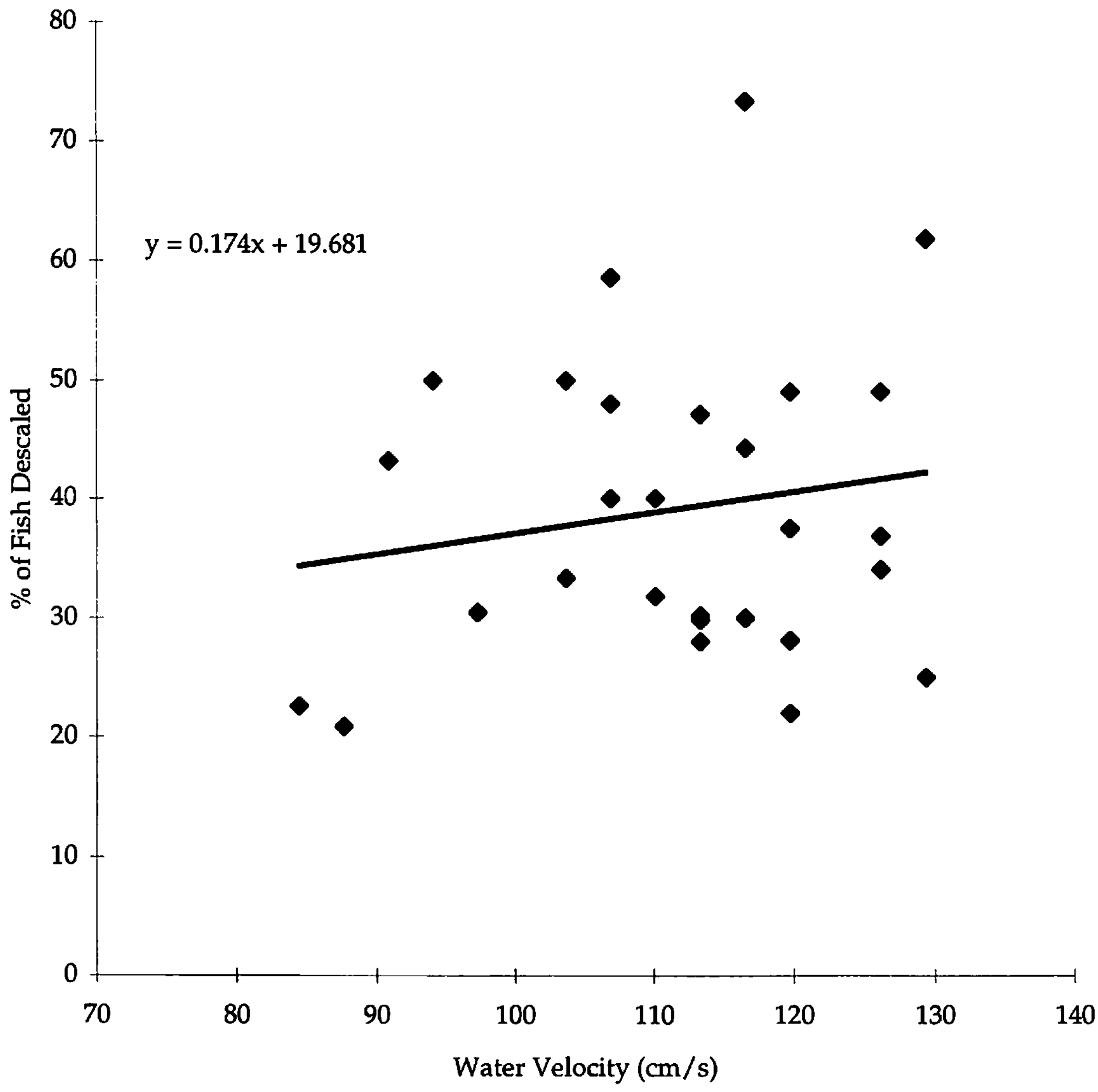



Figure B.8. - Relation of chinook salmon descaling frequency to water velocity at the upper site, 1996.

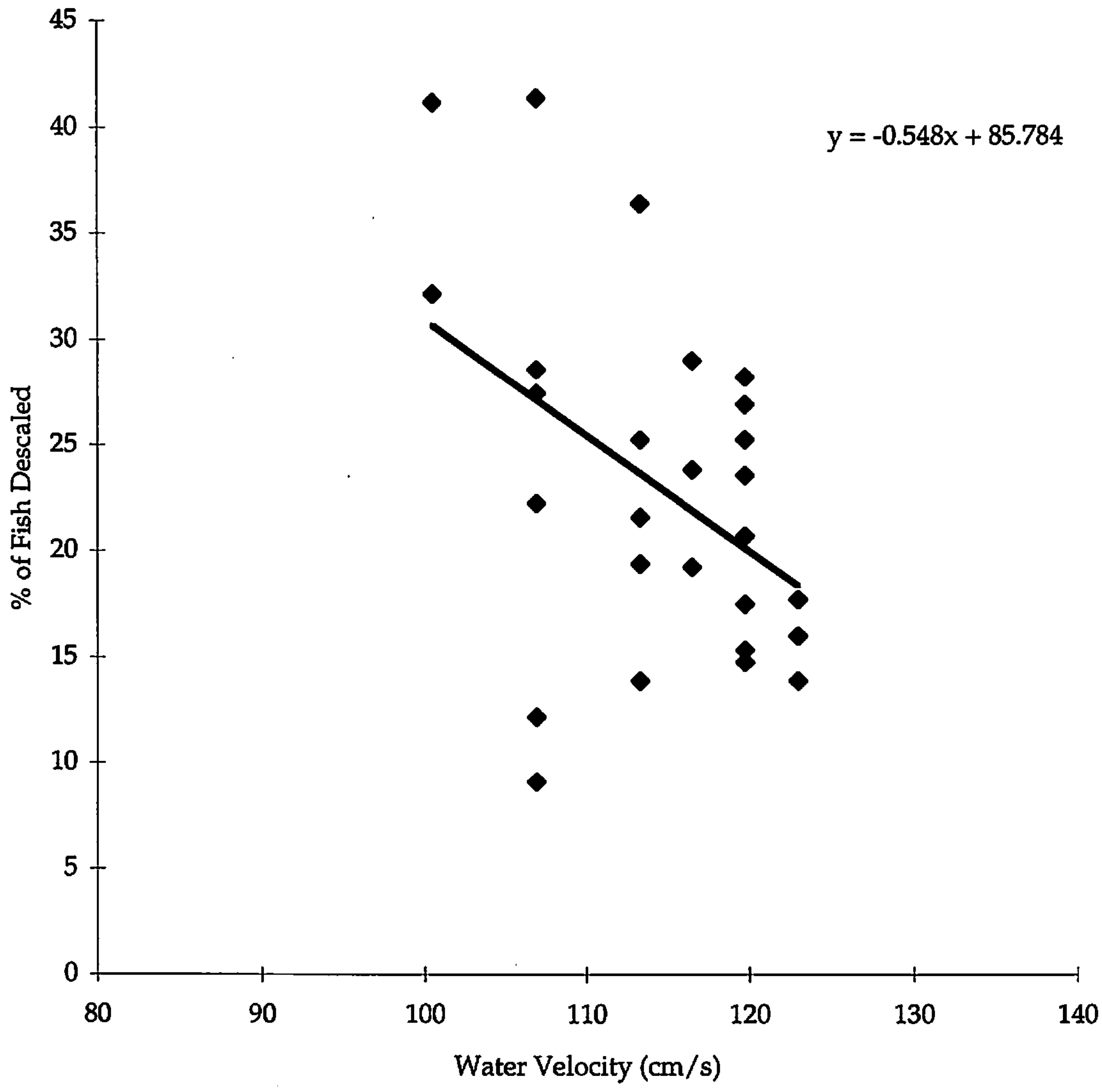



Figure B.9. - Relation of chinook salmon descaling frequency to water velocity at the lower site, 1996.

# Appendix C

## Daily Chinook Salmon Descaling Frequency Tables by Site and Year

Table C.1. - Chinook salmon descaling frequency at the upper site, 1995.

| Date | Water Velocity (cm/s) | Captured (N) | Descaled (N) | % Descaled |
|---|---|---|---|---|
| 5/22/95 | 68 | 2 | 1 | 50 |
| 5/23/95 | 65 | 4 | 1 | 25 |
| 5/24/95 | 70 | 2 | 0 | 0 |
| 5/25/95 | 65 | 2 | 1 | 50 |
| 5/26/95 | 60 | 0 | 0 | 0 |
| 5/27/95 | 63 | 1 | 0 | 0 |
| Totals | | 11 | 3 | 27 |

Table C.2. - Chinook salmon descaling frequency at the lower site, 1995.

| Date | Water Velocity (cm/s) | Captured (N) | Descaled (N) | % Descaled |
|---|---|---|---|---|
| 5/22/95 | 110 | 0 | 0 | 0 |
| 5/23/95 | 101 | 33 | 3 | 9 |
| 5/24/95 | 94 | 13 | 0 | 0 |
| 5/25/95 | 107 | 13 | 0 | 0 |
| 5/26/95 | 110 | 7 | 1 | 14 |
| 5/27/95 | 120 | 17 | 0 | 0 |
| 5/28/95 | 113 | 3 | 0 | 0 |
| 5/29/95 | 110 | 1 | 0 | 0 |
| 5/30/95 | 104 | 1 | 0 | 0 |
| 6/1/95 | 107 | 1 | 0 | 0 |
| 6/3/95 | 101 | 1 | 1 | 100 |
| 6/4/95 | 123 | 28 | 0 | 0 |
| 6/5/95 | 120 | 2 | 0 | 0 |
| 6/6/95 | 110 | 1 | 0 | 0 |
| 6/28/95 | 129 | 14 | 0 | 0 |
| Totals | | 135 | 5 | 4 |

Table C.3. - Chinook salmon descaling frequency at the upper site, 1996.

| Date | Captured | Descaled | % Descaled | Partial Descaled | % Partial Descaled |
|---|---|---|---|---|---|
| 5/6/96 | 4 | 0 | 0 | 0 | 0 |
| 5/7/96 | 204 | 1 | 0 | 45 | 22 |
| 5/8/96 | 96 | 1 | 1 | 19 | 20 |
| 5/10/96 | 102 | 4 | 4 | 40 | 39 |
| 5/11/96 | 100 | 4 | 4 | 36 | 36 |
| 5/12/96 | 100 | 9 | 9 | 40 | 40 |
| 5/13/96 | 100 | 12 | 12 | 38 | 38 |
| 5/14/96 | 29 | 1 | 3 | 16 | 55 |
| 5/15/96 | 68 | 15 | 22 | 27 | 40 |
| 5/16/96 | 100 | 9 | 9 | 40 | 40 |
| 5/17/96 | 114 | 3 | 3 | 39 | 34 |
| 5/18/96 | 47 | 1 | 2 | 15 | 32 |
| 5/19/96 | 50 | 4 | 8 | 7 | 14 |
| 5/20/96 | 50 | 1 | 2 | 13 | 26 |
| 5/21/96 | 53 | 0 | 0 | 16 | 30 |
| 5/22/96 | 88 | 2 | 2 | 26 | 30 |
| 5/23/96 | 47 | 3 | 6 | 11 | 23 |
| 5/24/96 | 56 | 0 | 0 | 14 | 25 |
| 5/25/96 | 57 | 1 | 2 | 15 | 26 |
| 5/26/96 | 32 | 1 | 3 | 11 | 34 |
| 5/27/96 | 85 | 1 | 1 | 39 | 46 |
| 5/28/96 | 52 | 0 | 0 | 23 | 44 |
| 5/29/96 | 20 | 0 | 0 | 6 | 30 |
| 5/30/96 | 15 | 0 | 0 | 11 | 73 |
| 5/31/96 | 10 | 0 | 0 | 4 | 40 |
| 6/1/96 | 25 | 2 | 8 | 10 | 40 |
| 6/2/96 | 12 | 0 | 0 | 4 | 33 |
| 6/3/96 | 18 | 1 | 6 | 8 | 44 |
| 6/4/96 | 23 | 1 | 4 | 6 | 26 |
| 6/5/96 | 3 | 0 | 0 | 1 | 33 |
| 6/6/96 | 3 | 0 | 0 | 0 | 0 |
| 6/7/96 | 3 | 0 | 0 | 1 | 33 |
| 6/8/96 | 2 | 0 | 0 | 1 | 50 |
| 6/9/96 | 1 | 0 | 0 | 1 | 100 |
| 6/10/96 | 3 | 0 | 0 | 1 | 33 |
| Totals | 1,772 | 77 | 4 | 584 | 33 |

Table C.4. - Chinook salmon descaling frequency at the middle site, 1996.

| Date | Captured | Descaled | % Descaled | Partial Descaled | % Partial Descaled |
|---|---|---|---|---|---|
| 5/8/96 | 67 | 2 | 3 | 13 | 19 |
| 5/9/96 | 131 | 0 | 0 | 36 | 27 |
| 5/10/96 | 104 | 0 | 0 | 33 | 32 |
| 5/11/96 | 110 | 1 | 1 | 32 | 29 |
| 5/12/96 | 113 | 0 | 0 | 18 | 16 |
| 5/13/96 | 87 | 1 | 1 | 13 | 15 |
| 5/14/96 | 20 | 0 | 0 | 6 | 30 |
| 5/15/96 | 79 | 0 | 0 | 19 | 24 |
| 5/16/96 | 68 | 0 | 0 | 9 | 13 |
| 5/17/96 | 72 | 1 | 1 | 8 | 11 |
| 5/18/96 | 33 | 0 | 0 | 3 | 9 |
| 5/19/96 | 41 | 2 | 5 | 14 | 34 |
| 5/20/96 | 52 | 2 | 4 | 15 | 29 |
| 5/21/96 | 57 | 0 | 0 | 13 | 23 |
| 5/22/96 | 31 | 0 | 0 | 8 | 26 |
| 5/23/96 | 97 | 2 | 2 | 28 | 29 |
| 5/24/96 | 76 | 1 | 1 | 20 | 26 |
| 5/25/96 | 84 | 2 | 2 | 26 | 31 |
| 5/26/96 | 24 | 1 | 4 | 10 | 42 |
| 5/27/96 | 22 | 1 | 5 | 6 | 27 |
| 5/28/96 | 15 | 0 | 0 | 6 | 40 |
| 5/29/96 | 15 | 1 | 7 | 10 | 67 |
| 5/30/96 | 11 | 1 | 9 | 3 | 27 |
| 5/31/96 | 4 | 0 | 0 | 0 | 0 |
| 6/1/96 | 12 | 1 | 8 | 2 | 17 |
| 6/2/96 | 10 | 0 | 0 | 1 | 10 |
| 6/3/96 | 8 | 0 | 0 | 0 | 0 |
| 6/4/96 | 2 | 0 | 0 | 1 | 50 |
| 6/5/96 | 9 | 0 | 0 | 0 | 0 |
| 6/6/96 | 4 | 0 | 0 | 1 | 25 |
| 6/7/96 | 3 | 0 | 0 | 0 | 0 |
| 6/8/96 | 1 | 0 | 0 | 0 | 0 |
| 6/9/96 | 3 | 0 | 0 | 1 | 33 |
| 6/10/96 | 3 | 0 | 0 | 1 | 33 |
| Totals | 1,468 | 19 | 1 | 356 | 24 |

Table C.5. - Chinook salmon descaling frequency at the lower site, 1996.

| Date | Captured | Descaled | % Descaled | Partial Descaled | % Partial Descaled |
|---|---|---|---|---|---|
| 5/6/96 | 140 | 1 | 1 | 44 | 31 |
| 5/7/96 | 294 | 9 | 3 | 98 | 33 |
| 5/8/96 | 96 | 0 | 0 | 17 | 18 |
| 5/9/96 | 234 | 4 | 2 | 59 | 25 |
| 5/10/96 | 105 | 4 | 4 | 21 | 20 |
| 5/11/96 | 122 | 1 | 1 | 17 | 14 |
| 5/12/96 | 124 | 1 | 1 | 18 | 15 |
| 5/13/96 | 103 | 0 | 0 | 18 | 17 |
| 5/14/96 | 78 | 0 | 0 | 22 | 28 |
| 5/15/96 | 93 | 4 | 4 | 14 | 15 |
| 5/16/96 | 100 | 0 | 0 | 29 | 29 |
| 5/17/96 | 102 | 0 | 0 | 22 | 22 |
| 5/18/96 | 101 | 0 | 0 | 14 | 14 |
| 5/19/96 | 54 | 0 | 0 | 12 | 22 |
| 5/20/96 | 107 | 1 | 1 | 12 | 11 |
| 5/21/96 | 105 | 2 | 2 | 28 | 27 |
| 5/22/96 | 102 | 0 | 0 | 28 | 27 |
| 5/23/96 | 103 | 0 | 0 | 26 | 25 |
| 5/24/96 | 101 | 2 | 2 | 12 | 12 |
| 5/25/96 | 104 | 0 | 0 | 20 | 19 |
| 5/26/96 | 100 | 4 | 4 | 12 | 12 |
| 5/27/96 | 103 | 0 | 0 | 26 | 25 |
| 5/28/96 | 102 | 5 | 5 | 19 | 19 |
| 5/29/96 | 29 | 1 | 3 | 5 | 17 |
| 5/30/96 | 11 | 0 | 0 | 1 | 9 |
| 5/31/96 | 14 | 0 | 0 | 4 | 29 |
| 6/1/96 | 29 | 3 | 10 | 9 | 31 |
| 6/2/96 | 17 | 1 | 6 | 6 | 35 |
| 6/3/96 | 5 | 0 | 0 | 2 | 40 |
| 6/4/96 | 4 | 0 | 0 | 2 | 50 |
| 6/5/96 | 1 | 0 | 0 | 1 | 100 |
| 6/6/96 | 1 | 0 | 0 | 0 | 0 |
| 6/7/96 | 1 | 0 | 0 | 1 | 100 |
| 6/8/96 | 2 | 0 | 0 | 1 | 50 |
| 6/9/96 | 1 | 0 | 0 | 0 | 0 |
| 6/10/96 | 2 | 1 | 50 | 0 | 0 |
| Totals | 2,790 | 44 | 2 | 620 | 22 |

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